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Aerial Characteristics (Data Sheet)—Part 5


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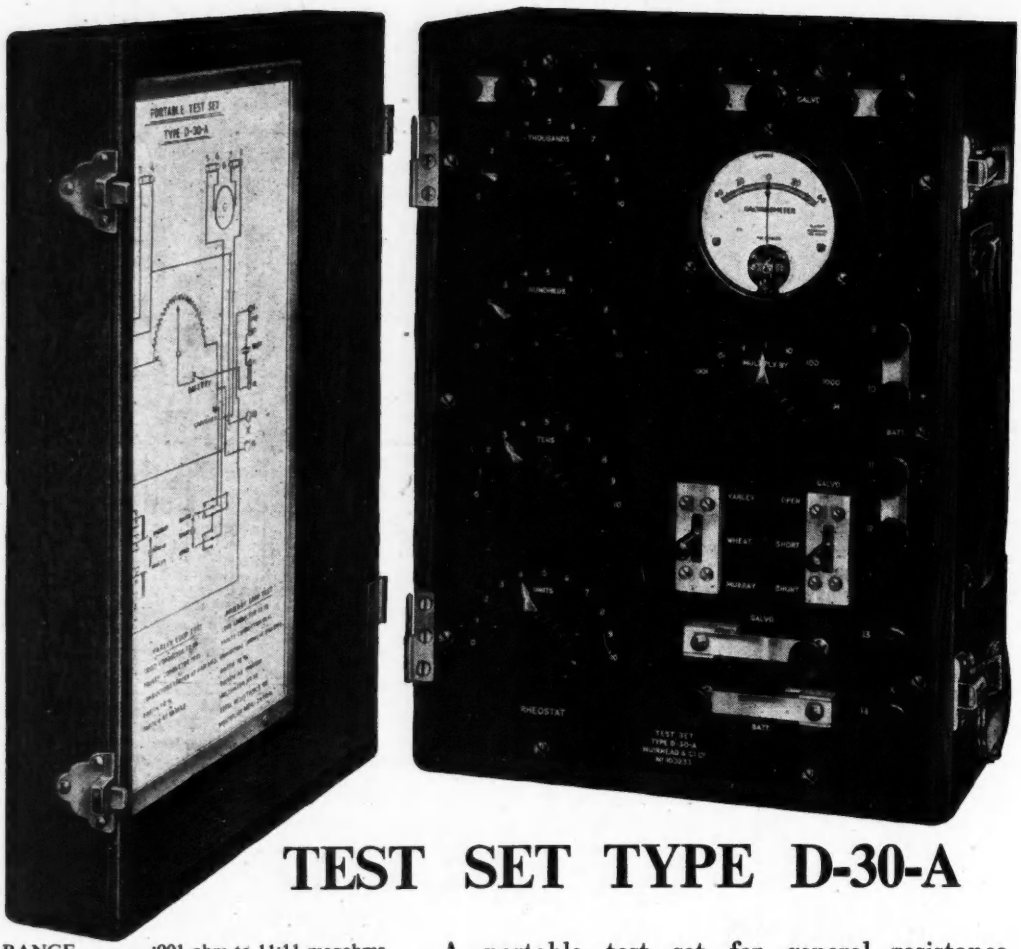


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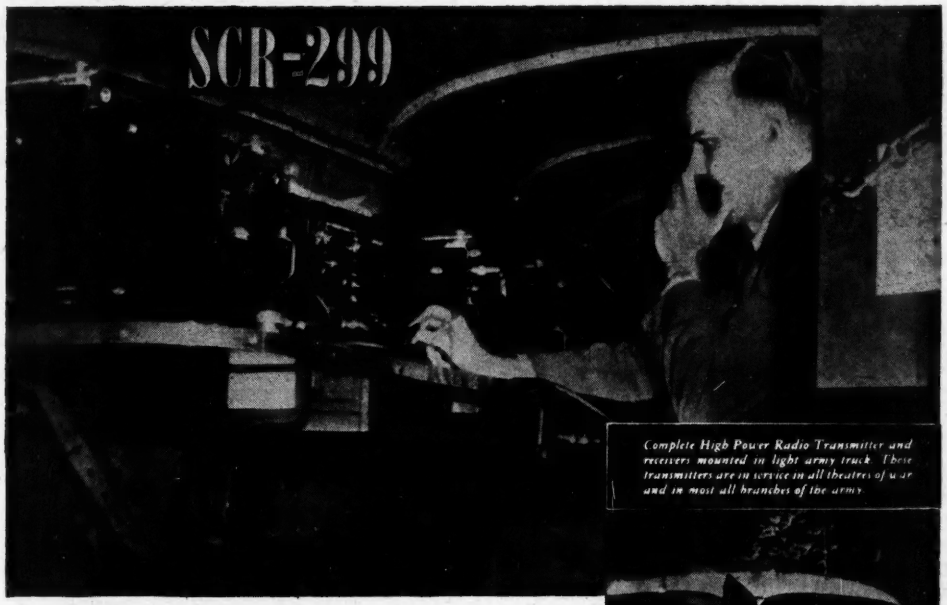


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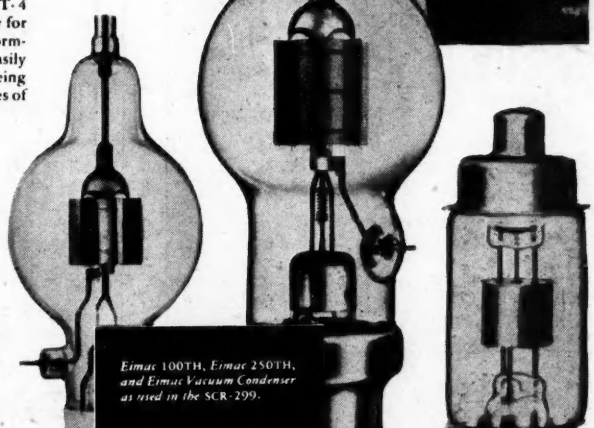

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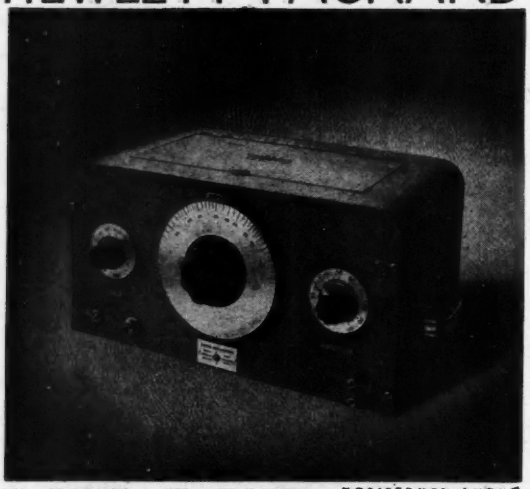

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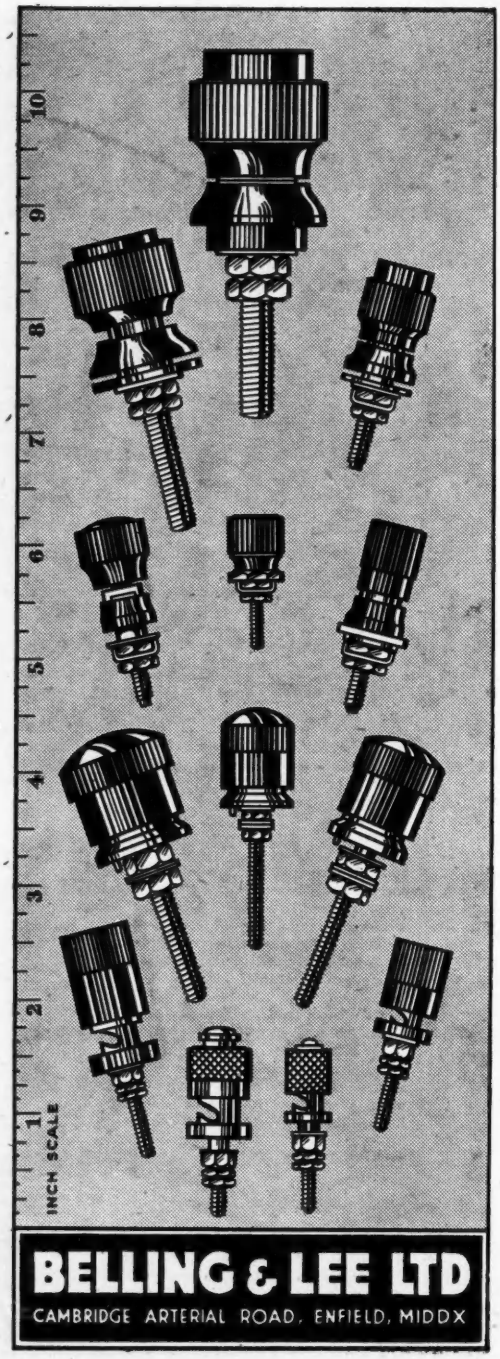


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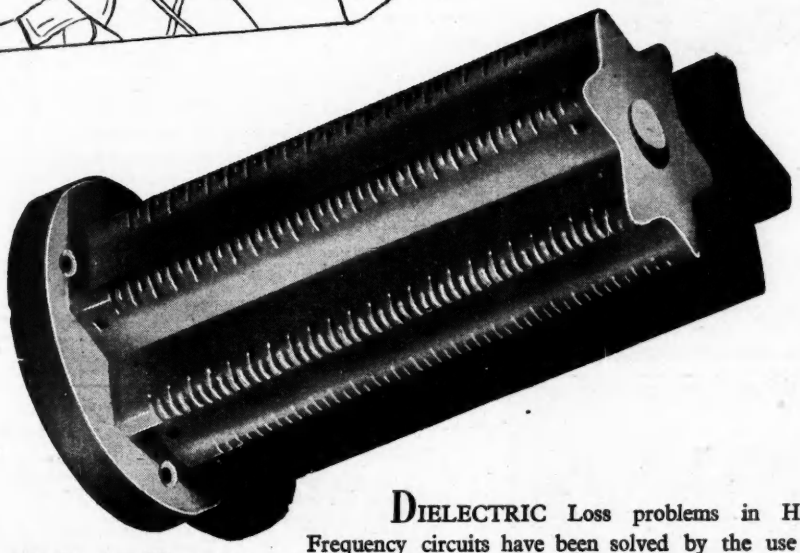

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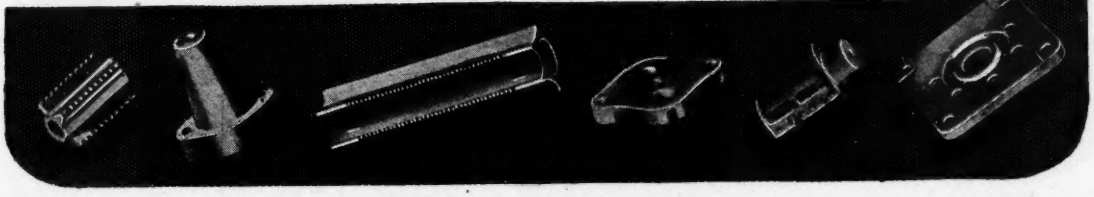

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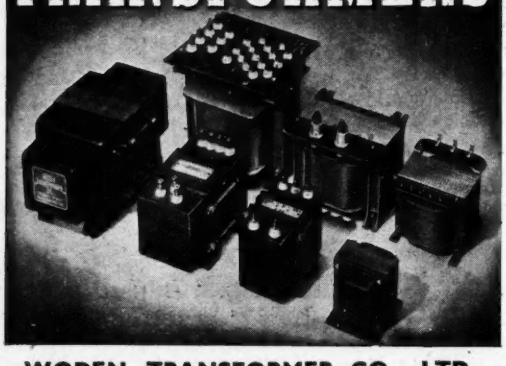

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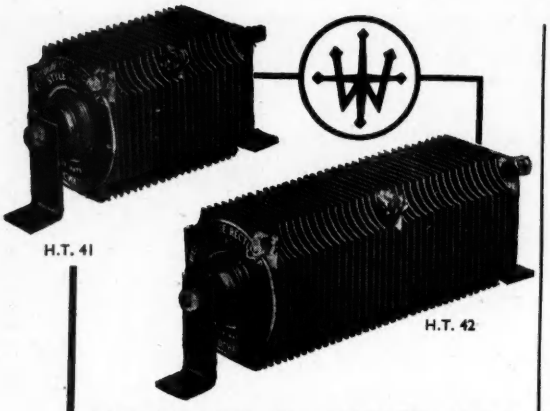


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JANUARY, 1944

Volume XVI. No. 191.

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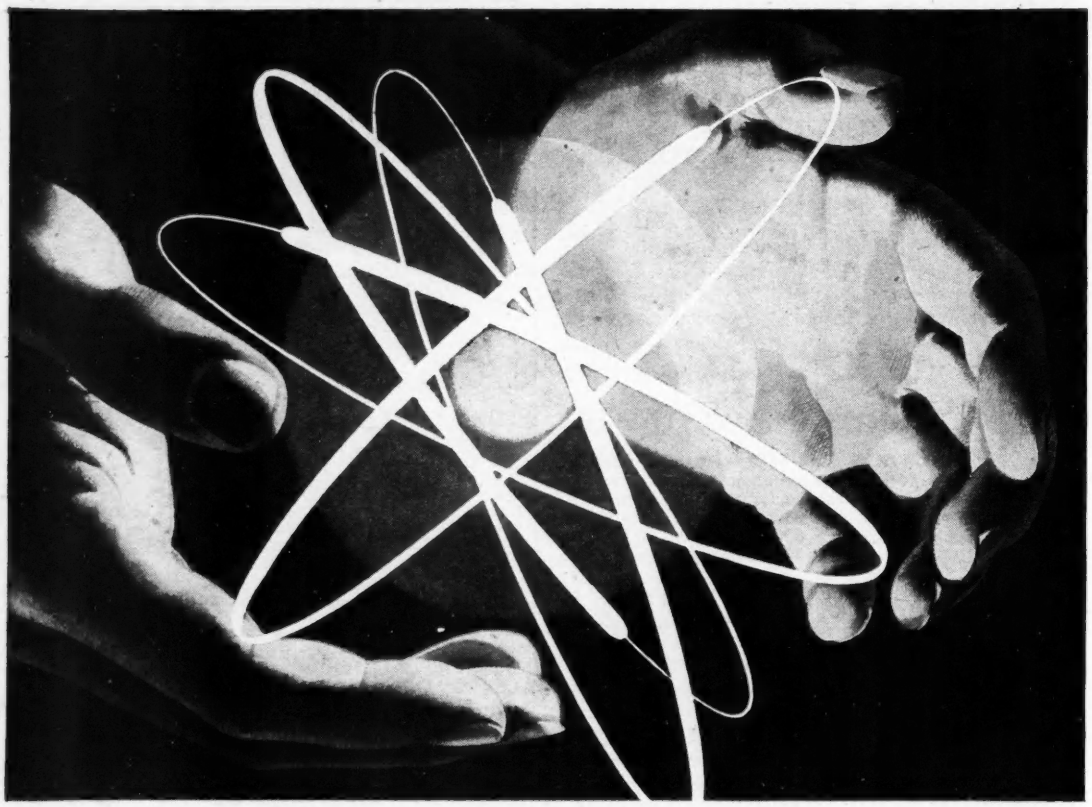

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# Edison Effects

THE year 1943 marks the sixtieth anniversary of the discovery by Edison of the effect which bears his name and which has proved the foundation of electronic engineering.

Although, as Mr. TYNE describes[1], the effect was widely discussed in scientific circles in this country and America, there is little mention of it in the popular biographies of Edison—possibly it had less spectacular appeal than his well-known inventions, and like many of his discoveries, was in advance of its time.

Mention of the Edison effect also calls to mind the early observations which he made on transmission without wires and a scheme patented by him in 1885 for communication between ships at sea[2]. The drawing filed with this patent shows an aerial slung between two masts and suggestions for broadcasting towers. This patent was subsequently sold to the Marconi Co.

Ten years earlier Edison had noticed a peculiar sparking which took place when a vibrator was being operated and studied it by means of what must have been the first adjustable spark gap. He suggested that a new form of energy was involved in the spark discharge and coined the word "etheric force" to describe it.

It is probable that Hertz' researches were carried out in ignorance of any experiments that Edison may have done, but Sir Oliver Lodge certainly knew of them, and although both he and Silvanus Thompson favoured an explanation based on known principles, he considered that discovery was part of the general shape of things to come.

Throughout the various records of Edison's work there are continual notes of experiments and apparatus which have laid the foundations of modern telecommunication — the carbon microphone, the induction coil in telephony, loud-speakers, and condenser microphones.

His loud-speaking telephone made use of the variation in friction between a metallic conductor and a semi-conductor when current was passing, an effect which was demonstrated by Johnson and Rahbek in another form over forty years later.

Incidentally, Edison was probably the first to institute practical training classes for servicemen in which he inserted artificial faults in apparatus and left them to find them out in a given time!

Not all Edison's inventions had the high originality of his phonograph or printing telegraph, but they were all the practical outcome of thinking on practical lines. His detractors called him "the great empiricist," but his empirical formulae worked, and most of the critics who condemned his inventions on theoretical grounds had to eat their words.

Thanks to the generosity of Mr. Ford, the Edison laboratories at Menlo Park are preserved in their original form. If Edison's experimental notebooks were widely available in their original form they would be worth many textbooks and serve as a valuable reminder of one of the greatest inventive geniuses of our time.

[1] See ELECTRONIC ENGINEERING, Dec. 1943 issue.
[2] Patent No. 465971 U.S.A.

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*by E. G. Couzens, B.Sc., A.R.C.S. and W. G. Wearmouth, Ph.D., F.Inst.P.*

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# Variable Frequency Resistance Capacity Oscillators

By J. A. B. DAVIDSON, B.A.*

ALTHOUGH oscillators producing sinusoidal waveform and tuned by resistance-capacity elements only are over twenty years old, it is only during the past few years that their commercial development has been appreciable.

Owing perhaps to the familiarity of the multivibrator in laboratory technique, some experimenters are inclined to look upon the resistance-capacity oscillator as a device in which frequency instability and poor waveform are inherent. It is one of the objects of this paper to outline the progress which has been made in development and to show that nowadays a well-designed RC oscillator has nothing to fear by comparison with more established types. It is felt that the most valuable contribution to the subject would be to discuss the general characteristics and behaviour of such types of oscillators, at the same time pointing out certain important design considerations.

As a review of this character within the scope of a single article cannot discuss the various circuits described in other than general terms the reader's attention is directed to the papers and specifications described in the bibliography† which refer to these circuits in much greater detail.

The second part of the article deals with what is known as the "Decade Oscillator," that is an oscillator in which the frequency is made direct reading on decade dials. This method of tuning possesses marked advantages over conventional systems and cannot be obtained by the use of LC oscillatory circuits. The writer's thanks are due to Messrs. Muirhead & Co., Ltd., in whose laboratory the development of the "Decade" and other RC oscillators has been carried out, for permission to publish certain material contained in this paper.

### General Considerations

Resistance-capacity oscillators are usually of the feed-back type, that is, they comprise an amplifier coupled back on itself in such a manner that oscillations are generated. The general conditions for oscillations to occur in such a system are that the loop gain from the input of the amplifier through the chain back to the input shall be unity and the loop phase shift shall be zero or a multiple of $2\pi$. For the oscillations to be sinusoidal, these conditions should hold for one frequency only at one time. As is well known, the less the tendency to oscillate at other frequencies, the greater will be the stability and purity of the derived oscillations.

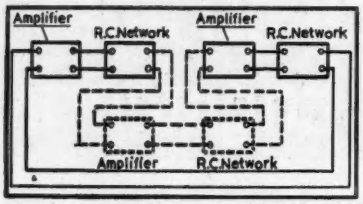



Fig. 1. General arrangement of R-C oscillator

In the most general terms the resistance-capacity oscillator consists of a closed chain of amplifying sections coupled together by resistance-capacity networks, as in Fig. 1. The networks determine the frequency of oscillation, *i.e.*, the frequency at which the loop phase shift is zero.

In Fig. 2 is shown an oscillator of the 3-stage type due to Van der Pol and Van der Mark. It will be seen that the net phase shift produced by the valves is 180°, consequently, the three coupling networks $CR$ must also produce a phase shift of 180°. If the networks are similar, as shown in the figure, each produces a phase shift of 60°. Assuming that the anode feed resistances $r$ are small compared with the resistances $R$ and the valve impedances, the maintenance condition is,

$$r.g. = 2.$$

Where $g$ is the mutual conductance of the valves (assumed the same for each).

The frequency of oscillation is given by

$$\frac{1}{2\pi\sqrt{3}\,CR}$$

It is convenient at this point to subdivide RC oscillators into two main types. The general type, as shown in Fig. 1, we will call type A. Those oscillators which employ one amplifying stage and one RC network we will call type B. It is to be noted that the type B is a special case of the type A oscillator, and further, that most of the type A oscillators can be transformed into type B. The distinction is made because the type B oscillators possess marked advantages over the general type.

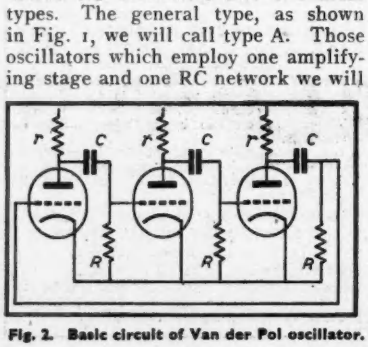



Fig. 2. Basic circuit of Van der Pol oscillator.

These are as follows: (1) The phase- and attenuation characteristics of RC networks are influenced by the terminating impedances. In the oscillator of Fig. 2, for instance, we have three frequency-determining networks each connected between the anode of one valve and the grid of the next. Each of the anode and grid impedances will therefore play some part in the determination of frequency.

If, on the other hand, two of the coupling networks are arranged to have negligible phase shift at the desired frequency, and the third coupling network is arranged to produce the whole of the required 180° phase shift, we have only one set of terminating impedances which can substantially affect the frequency. (2) The reduction of the number of amplifying stages to one simplifies the designer's task considerably, as the problem then becomes one of designing as perfect an amplifier as possible and connecting a suitable network between its input and output circuit. In particular, he is enabled to take advantage of negative feedback principles in his amplifier design. This is particularly beneficial in the present case, as not only are the unwanted phase shifts within the amplifier reduced, but the amplifier output impedance can be reduced and the input impedance increased. As ideally the RC network should be fed from a zero impedance source and should be terminated by an infinite impedance, this benefit conferred by negative feed-back is considerable.

It should be stated that when negative feed-back is applied to oscillators the usual advantages associated with its application to amplifiers do not all make their appearance.

In particular, the oscillation amplitude does not become substantially independent of valve or supply voltage changes, nor is the harmonic content reduced. However great the negative feed-back may be, positive feed-back must be present in order that the system may oscillate and when the circuit is on the verge of oscillation it is just as much in a state of unstable equilibrium as if there were no nega-

* Messrs. Muirhead & Co, Ltd.
† To be published at end of Part 2.

tive feed-back present. The reason why the harmonic content is not reduced is that non-linearity in the system is the only factor that limits the amplitude of oscillation. The only difference produced by negative feed-back in this respect is that the required degree of non-linearity will not be reached until the amplitude is greater than when negative feed-back is absent. However, the advantages that do appear, as previously stated, are that the amplifier phase shift and its output impedance are reduced while the amplifier input impedance is increased. The output impedance will have some influence on the frequency and should be made as small as possible while the input impedance is obviously required to be high in comparison with R and C in parallel.

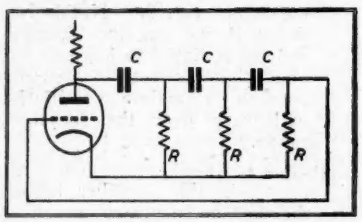



**Fig. 3. Basic circuit of Nichols oscillator.**

### Practical Oscillator Circuits

The first oscillator circuit tuned by resistances and condensers and containing no inductances appears to be due to Nicholls.[2] This circuit has been modernised and fully described by Ginzton and Hollingsworth,[3] and it will therefore be only briefly referred to here. The basic circuit is shown in Fig. 3:

In this circuit the valve introduces a phase shift of 180° while the network causes a further phase shift of 180° at a frequency given by

$$f = \frac{1}{2\pi\sqrt{6\,CR}}$$

The stage gain necessary for maintaining oscillation is 29. It will be noticed that the frequency is proportional to $\frac{1}{C}$ instead of $\frac{1}{\sqrt{C}}$ as in LC oscillators. Consequently, if ganged variable air condensers are used, it is a simple matter to obtain a 10:1 frequency sweep. In order to change range, it is simply necessary to alter the resistances $R$ simultaneously. This general procedure for tuning can be used with all types of RC oscillators.

The type A version of this oscillator was developed by Van der Pol and Van der Mark.[1] The circuit has already been given in Fig. 2. The frequency of oscillation is

$$f = \frac{1}{2\pi\sqrt{3\,CR}}$$

and the maintenance condition is $r.g. = 2$. It is to be noted that the gain required to maintain oscillations in this, as in most other RC oscillators, is quite small and easy of attainment with any valve amplifier. It is therefore, possible, using pentodes with a slope of 5 mA/V, to employ anode resistances of 400 ohms, thus fulfilling the required condition that $r$ is small and also ensuring that the stray capacitances from anode to earth will have little effect upon the frequency. An interesting feature of this particular circuit is that when the resistances $r$ have the same value and the mutual conductances of the valves are equal, the alternating voltages on each anode will be equal in amplitude and 120° apart[4]. It is thus possible with this circuit to produce a variable frequency three-phase supply.

An oscillator making use of two valves is that due to Willans and Yates-Fish.[5, 6] The basic circuit is given in Fig. 4.

The circuit consists of a phase advancing stage followed by a phase retarding stage. At a frequency determined mainly by the C's and R's the two effects compensate each other and the loop phase shift is 360° due to the valves only. Again assuming that the $r$'s are small in comparison with the valve impedances and the resistances $R$, the condition for maintenance is $r.g. = \sqrt{2}$. The necessary stage gain is thus even less than in the three valve oscillator and the number of stray capacities affecting the frequency is smaller. The frequency of oscillation is given by

$$f = \frac{1}{2\pi RC}$$

The type B version of the above circuit originated by Willans[7] in this country—although it seems to have made a separate appearance in the

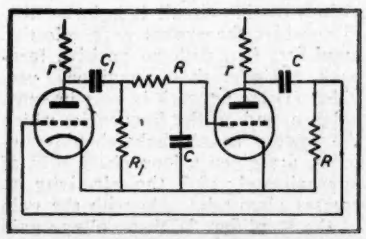



**Fig. 4. Basic circuit of Willans—Yates-Fish oscillator. C' and R' are of such values as to cause negligible phase shift at oscillation frequency.**

United States,[8]—is the circuit to which the most attention has been paid and is in some important respects the most satisfactory circuit which has so far been developed. The basic circuit is shown in Fig. 5:

The RC network forming the feed-back path introduces zero phase shift between the voltages $E_o$ and $E_i$ at a frequency given by $f = \frac{1}{2\pi RC}$, and at this frequency the ratio $\frac{E_i}{E_o} = 1/3$. The amplifier gain necessary for oscillation is therefore 3 and the frequency of oscillation is equal to $f$ provided the impedance $Z_o$ looking back from the network to the amplifier is low compared with the imped-

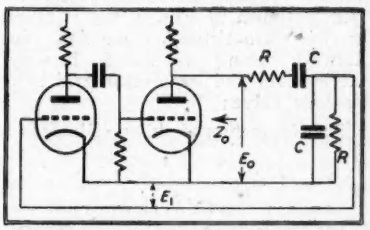



**Fig. 5. Basic circuit of Willans oscillator.**

ance of the network itself. The virtue of this circuit lies in the fact that it employs a two-stage low gain aperiodic amplifier, that is, precisely the kind of amplifier to which negative feed-back can be most easily and successfully applied. The circuit with the addition of negative feed-back is shown in Fig. 6:

The gain of the amplifier is given approximately by $\frac{R_a + R_b}{R_b}$.

A simple and effective form of A.V.C. can be applied to this oscillator by making $R_b$ a thermally controlled resistance such as a lamp with a positive temperature coefficient.[8] If for any reason the amplitude increases, the greater current through the lamp will increase its resistance and cut down the gain of the amplifier, thus tending to keep the amplitube at the same value. Furthermore, as the lamp resistance does not vary appreciably during a cycle of the oscillation frequency—down to, say, 20 cycles per second—it is not a source of harmonics and forms a means of obtaining a very pure waveform, as it can be arranged to limit oscillation amplitude before the valves run off the straight part of their characteristic. In practice, however this requires an H.T. supply

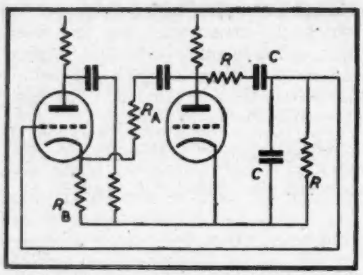



**Fig. 6. Willans oscillator with negative feedback.**

free from random fluctuations, as the lamp, owing to its thermal delay, will not operate against rapid changes in supply voltage.

A single valve RC oscillator has been described by Delaup[9, 10, 11] and others. In this oscillator, whose circuit is shown in Fig. 7, use is made of the "transitron" connexion, the network being connected between screen grid and suppressor grid of a pentode valve:

The frequency of this oscillator is:

$$f = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

Where $R_2$ is the resistance of $R$ in parallel with the plate resistance $R_p$ of the valve considering $g_2$ as the plate.

The maintenance condition is

$$G \geq -\frac{C_2}{C_1 R_1} - \frac{1}{R_2} - \frac{1}{R_1}$$

Where $G$ is the mutual conductance between $g_2$ and $g_3$.

The oscillator operates by virtue of the fact that at the frequency $f$ the voltages on $g_2$ and $g_3$ are in phase with each other and the transconductance between these two grids is negative. The transconductance obtained from a type 58 valve is stated to be of the order .00018 to .00035 mhos, while the average value for $R_p$ is 13,000 ohms. For good frequency stability obviously $R$ should be small compared with $R_p$, but the maintenance condition imposes a lower limit to $R$ even if $R_1$ is made high. The most favourable ratio of $\frac{R_p}{R_2}$ is about 4.3. This means roughly that a 5% change in the value of $R_p$ will produce a change of frequency of about 0.5%. Although this oscillator is not very suitable, therefore, for precision oscillators its simplicity makes it extremely useful for a laboratory hook-up, particularly when a low frequency oscillator is desired. In the paper referred to figures are given for tests made at 8 frequencies between 15 and 600 c.p.s. In every case the measured frequency was within 2% of the calculated frequency.

All the oscillators considered so far are characterised by having positive frequency-selective feedback networks. H. H. Scott[12] has introduced an oscillator which works on a fundamentally different principle. In this oscillator the network is of the null balance type. It is placed in the negative feedback path of an amplifier so that at the frequency of oscillation the negative feedback is zero, but at all other frequencies there is strong negative feedback. The net result is a highly selective amplifier to which a small amount of positive reaction is added to make the system oscillate at the frequency of selective amplification.

The basic circuit using a parallel-T network is shown in Fig. 8:

With the network shown the frequency of oscillation is given by $f = \frac{1}{2\pi RC}$. In order to maintain constant amplitude when the frequency is varied this oscillator requires simultaneous variation of three condensers or three resistances, but if a bridge network is used instead of the parallel-T circuit, the number of variables is reduced from three to two, although in this case a transformer will be required to obtain the necessary earthing conditions.

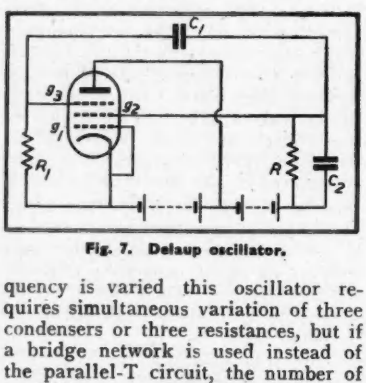



**Fig. 7. Delaup oscillator.**

In order to appreciate the possibilities of this circuit it is instructive to consider the system as a selective amplifier, *i.e.*, with no positive feedback. Under these conditions, provided (1) the network is kept in exact balance, and (2) the frequencies which the system as a whole should suppress, are given a loop phase shift of approximately 180°, the selectivity increases almost linearly with the gain of the amplifier. With a voltage gain of 2,000 a theoretical effective "Q" of 200 can be obtained using a bridge network, while the change of gain at the frequency of selective amplification due to supply voltage variations, etc., are no more than for a straightforward amplifier.

Thus, this circuit differs from those previously considered in that it can provide high selectivity without the use of positive feedback. It is, therefore, equally suitable for use as a selective amplifier, or if a small amount of positive feedback is introduced, as an oscillator.

There are, however, certain precautions to be taken if the best results are to be obtained; these are as follows:

(1) The amplifier should have high gain and low phase shift over the range of frequencies used.

(2) The bridge or Parallel-T network should remain in as exact balance as possible when the frequency determining elements are varied. If this condition is not met the harmonic content is liable to increase and also the amount of reaction necessary to maintain oscillation will vary over the frequency range.[13]

(3) It is advisable to provide sharp cut-off in the amplifier beyond the usable frequency range in order to prevent appreciable positive feedback through the negative feedback path at any frequency. For instance, examination of the basic circuit of Fig. 8 will show that the coupling circuits between the valves can make the system behave as a Van der Pol oscillator unless suitable precautions are taken to avoid this. For low frequency work in particular, a D.C. amplifier is desirable.

Provided these conditions are met the harmonic content will be small and the frequency instability due to unwanted phase shifts will also be small.

It is worth pointing out that this application of negative feedback is by no means confined to RC circuits. Remarkable results in the increase of selectivity of tuned LC circuits have been achieved on this principle.[8]

### General Behaviour

It is essential to note that all RC oscillators are of the reduced reaction type, that is, just sufficient reaction is provided to maintain reliable oscillations. An excessive value of reaction always leads to poor results in the shape of bad waveform and frequency aberration, much more so than in a tuned circuit oscillator. Fortunately, the situation is saved by a valuable property of resistance capacity net-

works which is this: if we take such a network and vary the resistances or condensers simultaneously, keeping their ratios constant, the frequency for zero or 180° phase shift between the input and output voltages will be shifted up and down the frequency spectrum, but the transmission loss at this frequency will always be the same. This means in the case of most of the circuits considered that if we vary the network elements in this manner, the gain necessary for oscillation is constant at all frequencies. It is this property of RC networks which makes variable frequency oscillators possible at all. In order to achieve the maximum possible frequency range, RC oscillators are always provided with reaction control, either manual or automatic. The automatic control is very desirable when the oscillator is to be used by an unskilled operator, but for laboratory use in the hands of a skilled person the flexibility obtained by an intelligent use of the reaction control is very advantageous. For example, in a typical oscillator covering the range 20-20,000 c.p.s. the harmonic content at low reaction was less than 0.2%. The output voltage variations with frequency were considerable. With a high value of reaction the harmonic increased to 2%, but amplitude variations were cut down to ±0.5 db over the entire frequency range. The frequency change between the high and low values of reaction was quite negligible. The operator thus has an instrument which under his control can be made to have the characteristics most desirable for the purpose in view.

### Effect of Changes in Supply Voltages

The necessity for the "reduced reaction" makes the oscillator rather sensitive to variations in supply voltage. Such variations have a much greater effect on the output voltage than on the frequency. To give an example, in one particular oscillator without A.V.C. or stabilisation of any sort the effect of reducing supply voltages by 10% was to reduce the output voltage nearly to zero. Increasing the supply voltages by 10% increased the output voltage by 50% of its normal value. The frequency remained constant at 1,000 c.p.s. to ±0.1%. The provision of automatic volume control improves the position very considerably, but while A.V.C. circuits will take care of slow fluctuations their response is not rapid enough to take care of transients. It is in consequence usual for main driven oscillators to be fitted with voltage stabilisers to minimise trouble from this course. Once this has been done the effect of normal variations of mains voltage on the output level is quite small and the output of a typical oscillator will remain constant to 2% (quick and slow variations) for an indefinite period. Measurements made at 1,000 c.p.s. on a special oscillator of recent design showed frequency variations of ±.0010% and output voltage variations of ±3% for a mains voltage change of ±10%.

This oscillator was provided with a simple form of A.V.C. consisting of a lamp as previously described.

Variations of output amplitude are due to changes in gain of the valves in the amplifier section and are not appreciably affected by circuit design except in so far as this relates to the operating potentials on the valves. It is therefore rather important to choose valves which exhibit small changes in gain with variations of supply volts.

Any abnormal frequency variations caused by supply voltage changes are nearly always due to the presence of grid current in the valve which terminates the RC network.

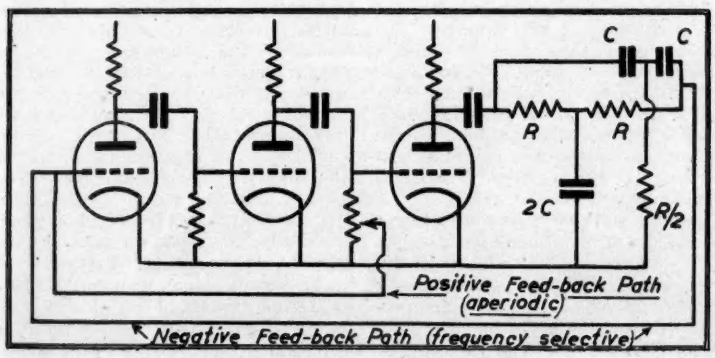



**Fig. 8. Basic circuit of Scott oscillator.**

### Frequency Range

The range of frequencies over which RC oscillators compare most favourably with other types is from less than 1 cycle per second up to about 200 kc/s. They can easily be made to oscillate at radio frequencies, but here they tend to be eclipsed by the normal tuned circuit oscillator because they are more sensitive to phase changes within the maintaining amplifier. In other words, they can be made to operate most successfully over the range of frequencies where amplifiers can be made substantially free from phase shift.

### Frequency Stability

This will, of course, be governed largely by the temperature coefficients and stability of the resistors and condensers used. A common practice is to employ composition resistors in view of the high resistance value required when variable air condensers are used. In this case the long period stability will not be better than 3 or 4%. Where wire-wound resistors are used the long period stability is likely to be at least ten times as good. The instability resulting from changes in amplifier constants due to ageing of valves, supply voltage variations, etc., should lie between 0.5% and 0.02% depending partly on design and partly on frequency. Any instability resulting from these causes will be more marked at the higher frequencies.

### Harmonic Content

It is extremely difficult to specify hard and fast figures for harmonic content as so much depends upon the amount of reaction employed. As has already been pointed out, harmonic content and constancy of output voltage over wide frequency ranges are bound up together, and improvement in the one always leads to deterioration of the other. It may be assumed, however, that where manual reaction control is fitted, the harmonic content can be reduced well below 0.5% while still preserving reliable oscillations. Where automatic volume control is fitted 1% total harmonic content may be regarded as a good figure provided the output voltage-frequency characteristic is reasonably flat. The harmonic content can be made to remain substantially constant over the entire frequency range and the same purity of waveform appears to be maintained at frequencies below 1 cycle per second, although here the only evidence is oscillographic records.

*(To be continued.)*

# U.H.F. and Post-War Broadcasting

by K. I. JONES & D. A. BELL*

**At an Informal meeting of the Wireless Section of the I.E.E. on November 16th last, a discussion was held on "The Role of U.H.F. in Post-War Broadcasting." The text of the authors' opening remarks, which is given below, will be read with interest by those who were unable to attend the meeting, and is worthy of careful consideration.**

IT is not premature to consider now the form that the Broadcasting Service should take in the post-war years.

The present system need not be regarded as final and unalterable if the development of radio technique makes change desirable and the Government obviously appreciated this when it granted a Charter to the B.B.C. for a limited period only. One may therefore ask whether a period has not now been reached when the experience gained in transmission and reception at the Ultra High frequencies could not be usefully applied to broadcasting.

The ultra high frequency band can be defined as lying between 300 and 30 Mc/s.—1-10 metres, and in the remarks which follow the lower frequency part of the band is considered as the most suitable for the Broadcasting and Television Services.

It is relevant first to consider briefly the future possibilities of the present system. The public undoubtedly expect that the many war developments in radio will be applied to improve and extend the broadcasting service and it is in the interest of the industry that these hopes should not be disappointed. An engineer may well wonder, however, whether any real advance is possible within the limits of the present medium- and long-wave broadcasting bands. Before the war the design of broadcasting receivers was becoming stabilised and even standardised; development departments vied with each other in producing new gadgets to attract the dilatory purchaser and Radiolympia was degenerating into a combined cabinet and Variety show. It is not suggested that a period of stable design is necessarily a bad thing for industry, or that broadcasting was losing its appeal, but what is suggested is that Radio is still too young to regard a hardening of its mental arteries with complacency. The present practically complete suspension of broadcasting receiver manufacture does present an ideal opportunity to consider the progress that has been made and to plan an orderly approach to new developments. We may hope that in the not far distant future we shall be able to turn again to peacetime designs and produce a completely new range of sound and television sets to meet the accumulated demand.

If we consider for a moment the chief war-time developments which may be applied to broadcasting receivers on the existing wavebands, these can be summarised under three headings :—

First, a miniature range of valves and components has been developed. (The other war-time valve developments are mainly useful at frequencies higher than the present broadcasting band.)

Secondly, great improvement has been made in performance of radio sets under extreme climatic conditions.

Thirdly, the frequency stability of tuned circuits, particularly at the higher frequencies, has been improved.

These improvements will hardly impress the non-technical public to whom only the first would be readily apparent. The miniature valves and components will certainly find application in certain specialised types of set such as the portable and the car-radio, but no engineer would regard a widespread reduction in the size of home sets with satisfaction, since the quality of reproduction must inevitably suffer unless a separate loudspeaker is used. The Americans have found it commercially unprofitable and are striving to increase the unit value of their sales. We should profit by their mistakes and discourage the Midget, as we did before the war, except as a second set for the bedroom or kitchen.

We may now turn to the advantages which the ultra high frequencies can offer and in passing consider briefly the alternative possibilities of line transmission.

Looking back at the history of broadcasting, new developments have always arisen through an extension of the frequency band towards the higher frequencies and this is a precedent which should be followed. A broadcasting service on the ultra high frequencies would provide a local service of high quality without restriction on the number of programmes and this would be a very acceptable development.

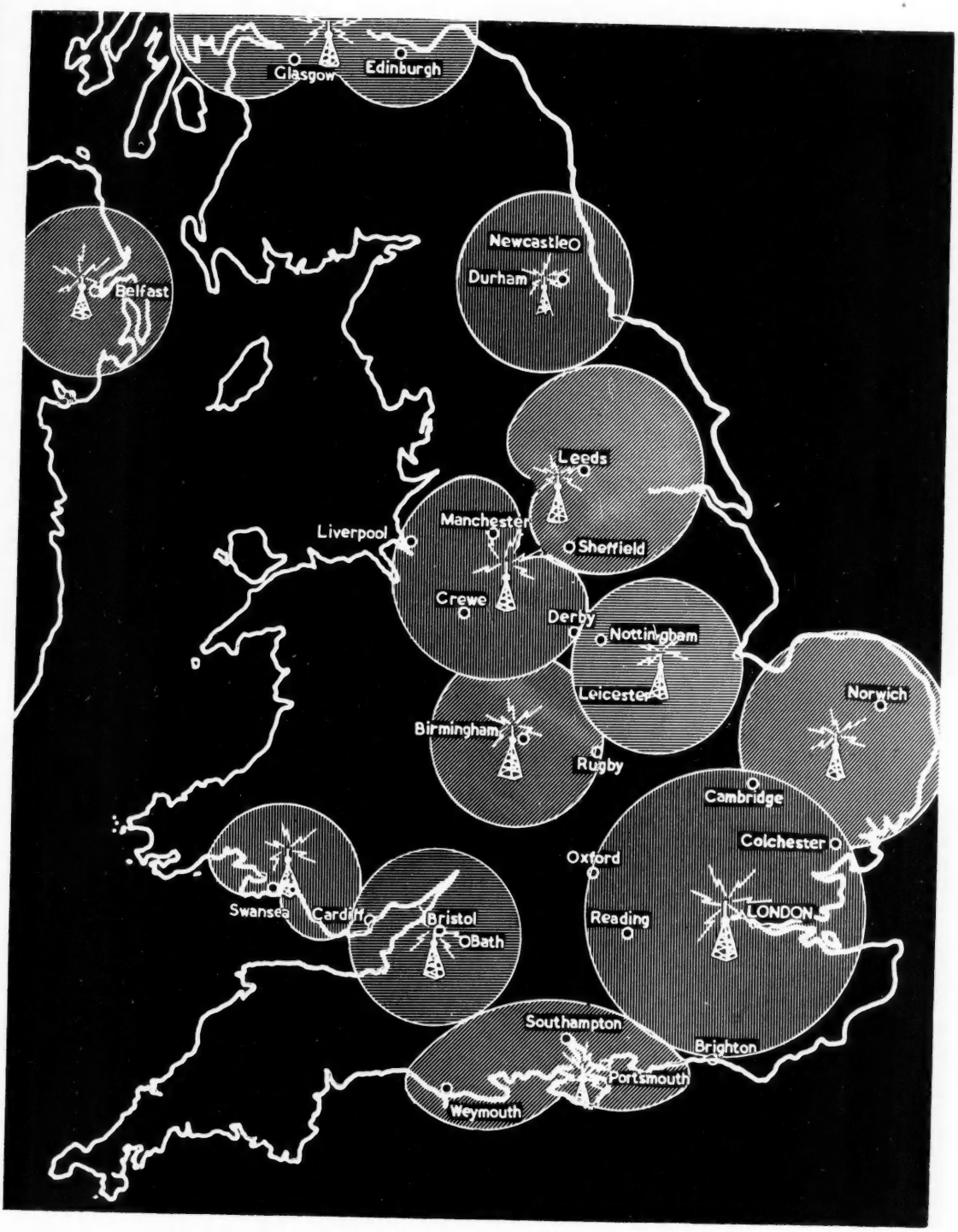
The desirability of such a service and the manner in which it is best achieved has been widely discussed recently. Frequency modulated transmission, by an open aerial at U.H.F. has not perhaps received the attention which its merits deserve. A reasonable number of stations could distribute programmes over the whole country more economically than by any other system. On the other hand, a system of distribution along closed lines suffers from the basic disadvantage that it is most applicable to areas with a dense population. If transmission by existing telephone or power lines is considered, high carrier frequencies must be used to accommodate a sufficient number of high quality channels, and the attenuation along the lines becomes a further difficulty. A serious objection to this proposal is that it could not distribute nationally a television programme, therefore transmission at U.H.F. would also be necessary. Thus the choice is U.H.F. *and* line distribution *or* U.H.F. distribution only. The latter seems an obvious choice, since similar transmission equipment could be used for sound programmes of ordinary broadcasting and television. Radio links on a centimetre wavelength would normally be used to link the transmitters with the studio and one such link could carry the television programme and a number of sound programmes.

A further possible system may be mentioned: the transmission of programmes direct to the listener by special U.H.F. cables. This method is free from the objection levelled against transmission by existing cables but is rejected by reason of its prohibitive cost. The proposed new service would be additional to the existing broadcasting stations on long, medium and short waves, the existing type of radio set is therefore still required but with an additional wavelength range. The natural desire to listen to foreign programmes should be encouraged as it promotes better understanding between nations; a freedom which a democracy has a right to expect. No new transmission system should be considered which encouraged the use of a set which could only receive local programmes. The cost of the receiver would not be appreciably affected whether line or broadcasting distribution is chosen.

The details of this technical plan put forward for discussion can now be considered. It is for the extension of sound broadcasting to the U.H.F. band using frequency modulation, and going forward with a nation-wide television service; owing to the quasi-optical transmission characteristics of

* Messrs. A. C. Cossor.

# Blue Print for Television




Frequency Bands used for various regions are distinguished by different shading

these frequencies it is necessarily on a Regional basis. To cover the populous areas of Great Britain and Northern Ireland at least twelve stations would be required. To avoid interference at the boundaries of their service areas no two adjacent transmitters can work on the same frequency.

Three different frequencies will satisfy this requirement distributed in a centred-hexagon pattern. (Each station on frequency No. 1 say, is surrounded by a ring of six stations alternately on frequencies Nos. 2 and 3 and these can form the centres of other rings of six, using either 1 and 2, or 1 and 3 frequencies). Then if we assume a service radius of about thirty miles the worst case would be a receiver thirty miles from one transmitter and seventy-five miles from another transmitter using the same frequency. Propagation measurements for the London television transmitter show that in daylight the field strength at a range of thirty miles is about ten times as great as that at seventy-five miles, a difference of 20 db.; a simple directional aerial at the receiver should be sufficient to eliminate any residual interference in cases like this.

It is believed that an initial coverage of all the more heavily populated regions could be obtained by twelve groups of transmitters, and these are shown on the map on p. 316.* It will be seen that London on frequency 3 is surrounded by East Anglia (Frequency 1), Grantham (Frequency 2), Birmingham (Frequency 1), Bristol (Frequency 2), and the South Coast (Frequency 1). Similarly arranged are areas centred on Manchester, Leeds, Durham, Edinburgh, Belfast and Swansea.

#### Frequency Bands

The frequency bands required must now be considered on the assumption that each regional station will transmit a vision and sound programme and a number of F.M. broadcast programmes. The band required for vision depends on the degree of definition of the picture. So many factors subjective, technical and economic are involved here that it is not surprising to find, as was shown in a recent discussion,† that there is no solid agreement as to optimum standards.

For the purpose of this study, we assume a standard well suited to a 9½° viewing angle (6:1 ratio), a visual acuity of 1 minute of angle and transmission at these carrier frequencies, namely 525 lines interlaced at 50 c/s. field frequency and requiring a modulation band width, at a conservative estimate, of 3.2 Mc/s.

We believe that the present standard of 405 lines is on the low side and recommend this 25 per cent. increase (which gives an increase in definition of 50 per cent.) unless there are insurmountable objections to this change.

Owing to the great demands on frequency allocation, it is suggested that the modified form of single-sideband transmission, known in America as "vestigial-sideband," should be employed (Fig. 2). In this system the impossible problem of obtaining a filter to cut completely one sideband without attenuating any part of the other, is avoided by using a suitably designed filter of which the transition between the pass and attenuation bands is centred on the carrier frequency; then the partial attenuation of the sidebands nearest the carrier on the side which is to be retained is compensated by the presence of residues of the corresponding sidebands on the side which is to be eliminated. The vision signal would thus require about 4 Mc/s. The accompanying sound would be F.M. with a swing of ± 75 Kc/s. Thus the total band is made up of 0.5 Mc/s. to the vision carrier plus 3.75 Mc/s. vision band plus .625 separation from sound carrier plus .125 Mc/s. to the end, totalling 5 Mc/s.

The argument has, of course, been based on the acceptance of a monochromatic picture. This basis is assumed because a picture adequate in both colour reproduction and definition would require a very much greater band-width. This could not be transmitted on the carrier frequencies envisaged in this plan, and would involve considerable difficulties in receiver design. It is, in fact, considered that the present development of television technique is not suited to the introduction of colour.

#### Frequency Modulation for Sound

The use of frequency modulation for sound broadcasting is, in our opinion, essential. A high quality transmission can only be fully appreciated if it is free from interference caused by atmospherics, electrical apparatus and other broadcasting stations. Experience gained from the London Television Service before the war proved that the interference from automobile ignition systems was a serious problem and most manufacturers of television sets incorporated some form of interference suppression circuit. The extension of the service to other regions may create interference from stations working on the same or an adjacent frequency. To both forms of interference F.M. appears a satisfactory solution. To adapt a comparison previously used, F.M. makes a fair signal perfect, a poor signal good, but a useless signal inaudible.

It has already been shown that three different sets of frequencies would be sufficient for a U.H.F. service covering the whole of the country, these being so arranged that no two adjacent stations work on the same carrier frequency. The actual frequencies have been obtained on the following basis: We require three television channels, each of 5 Mc/s. and we will assume that each

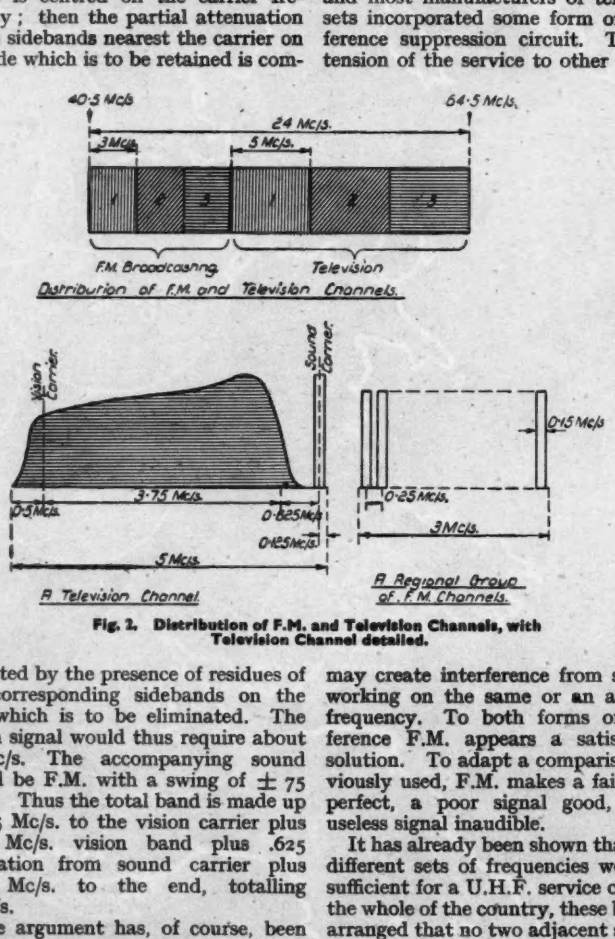



**Fig. 2. Distribution of F.M. and Television Channels, with Television Channel detailed.**

* The frequencies used for different regions are distinguished by varied types of shading on the map.

† See ELECTRONIC ENGINEERING, July, 1943, p. 60.

region has in addition a band of 3 Mc/s. for F.M. sound, so that the three regional allocations are each a band of 8 Mc/s., making a total of 24 Mc/s. in all. Before the war, frequencies up to 40.4 Mc/s. had been allocated to various services and at this point the European allocation showed a band of 18 Mc/s. shared by television and other services. In view of the improvements in technique at still higher frequencies, it can be argued that non-broadcasting services, such as directional and point-to-point services can function as well or better at 70-80 Mc/s. or higher as they could at 50-60 Mc/s.; for at 50-60 they were already limited to optical range for reliable service and at higher frequencies they would get better directional properties. It is therefore proposed to extend the U.H.F. broadcasting band to cover from 41 to 65 Mc/s. and the television stations have been put at the top so as to obtain a better ratio of carrier to modulation frequency.

**Allocation of Bands**

We are left with three bands of 3 Mc/s. each to allocate to 12 F.M. sound broadcasting transmitters; by allocating these in the same sequence as the vision bands, selectivity problems in the vision receiver are reduced. Thus, 47-50 Mc/s. sound broadcasting goes to the regions having 60-65 Mc/s. television, 44-47 Mc/s. goes with 55-60 Mc/s., and so on. The proposed standard for sound broadcasting is an audio frequency range up to 15 kc/s. and transmission by F.M. with a deviation ratio of 5. The nominal frequency sweep is then $\pm$ 75 kc/s. about the carrier frequency, but the band occupied may exceed 150 kc/s. owing to the existence of high-order sidebands and to accidental over-modulation; an allowance of 250 kc/s. per channel should be adopted provisionally and experience under working conditions would show whether it could be safely dropped to, say, 200 kc/s. On this basis we get twelve channels in each region; these are the "Primary" or first-grade sound channels, which can be used for transmitters of sufficient power to cover the whole region.

In addition, there are blocks of twelve "Secondary" channels, Type A, using the frequency bands allocated to adjacent regions, but so geographically sited and of such reduced power that interference did not occur. Similarly, twenty additional channels Type B could operate in the regional television band during those hours of the day when there is no television programme. These secondary channels would be used for broadcasts of local interest and broadcasts to schools.

Altogether then, any one place would have one television channel, twelve primary sound channels, twelve secondary sound channels Type A, and twenty Type B.

An important difference between the long- and medium-wave service and the U.H.F. service is now apparent. The former offers a maximum of two alternative programmes for each region, at U.H.F. the possibilities are vastly extended; with such possibilities, therefore, one may ask whether the continuation of a monopolistic service is necessary or desirable.

Without any implied criticism of the present system and without any championship of programmes sponsored by advertisers, it may still be considered that a judicious combination of the two has powerful advantages. Before the war the popularity of the sponsored English programmes from Continental stations was sufficiently demonstrated. It now becomes possible for these stations to operate in this country. The B.B.C. might welcome the opportunity to concentrate their resources on the more cultural programmes while the element of competition introduced might be beneficial. But it is not suggested that the system should be confined to advertising programmes. There would be no obstacle to Universities and County Authorities running broadcast educational services. Purely local news services and special agricultural programmes are another possibility. This proposal does not include the Television Service, since as it consists of a single programme it should obviously continue under B.B.C. control.

**Cost**

Programme cost in television is a point frequently considered to be a difficulty. This is serious, because the B.B.C. normally spent about three times as much on programmes as on engineering. One feature which helps is that the television service may, and in fact ought, to be run on shorter hours than sound broadcasting because it demands the whole attention of the viewer and the hours of leisure of the population are not yet as long as the hours of broadcasting; as no alternative programme is suggested there could be extensive relaying of the same programme to different television stations by suitable means. Moreover, a Television Service should not, in any sense, value a production in accordance with its cost, and there is no doubt that some of the most popular television items are direct transmission of topical and sporting occasions.

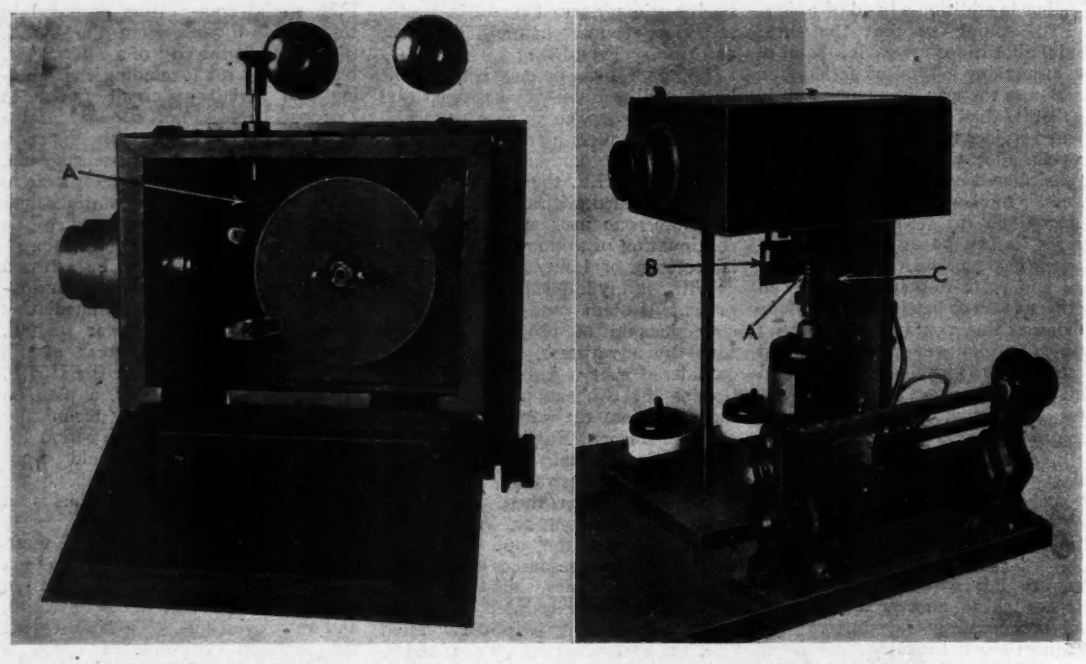
Apart from the B.B.C. television service, there remains the question of the financial aspect of the independent F.M. sound transmitters proposed in this plan. Figures from the U.S.A. (pre-war) put the cost of a 1 Kw. F.M. transmitting set (excluding the building and aerial) at about £2,000 to £2,500. This is not a considerable sum, the only appreciable expense, therefore, is the programme material.

There is thus no financial obstacle to independent broadcasting stations, and no necessity for all of them to be dominated by advertising interests.

In conclusion, it may be stressed that these proposals deal with developments which will be immediately available in the post-war period. Bearing in mind the great strides which have been made in the U.H.F. spectrum during the war, a plan on these lines is immediately technically applicable, and after a due period for preparation of designs, it could be put into operation, area by area, as the stations became available. This is an essential requirement. An early decision would enable the large numbers of receivers which will be made in the immediate post-war period to embody the necessary new features, and thus overcome, to a large extent the problem of obsolence which is usually a deterrent to the change of an existing system. This is a particularly important point to remember in connexion with the London television station. We are told that this has been largely dismantled. If it were restarted on the original system without due consideration of future possibilities, the problem of a subsequent change would be enormously complicated and the number of sets to be modified, greatly increased. If stations in other areas are built, manufacturers might find themselves making two different designs and the cost of each would be increased.

The actual frequencies mentioned are not rigid requirements of the scheme, but have been set out in detail to prove that the band-width required is not excessive. The number of lines which is optimum for a television picture has been shown to be a debatable subject, but one due for a careful reconsideration. The proposal to use F.M. for television sound is basic and inevitably linked with the plan for an extension of sound broadcasting to the Ultra High Frequency Band.

Now is the time to consider the extension and improvement of the Broadcasting Service of which we are all justly proud. Now is the time to plan to extend to the whole country the television service which, before the war, led the World. This plan is put forward to stimulate discussion on the best way to achieve these objects and we hope it will lead to their early and complete realisation.




The photographs show a drum camera made in the Rotax Laboratories. The worm A (right hand picture) with which the moving contact B engages, slides over the contact C to switch on the tube for an exact revolution of the drum. The plan view (left) shows the cassette in position and the link A for operating the cassette shutter.
The cassette and drum are shown in the centre column with a film in position. A is the cassette shutter and B the film clip.

# Photography of Cathode Ray Tube Traces

By N. HENDRY*

A lecture delivered before the Association for Scientific Photography at the I.E.E., Saturday, November 13th. 1943. This paper will be followed in next issue by one delivered by Mr. Nethercot (E.R.A.) at the same meeting.

IN designing or choosing equipment for cathode ray tube photography, the first consideration is the type of trace which it is required to record. These can be divided into four groups :

(*a*) Repetitive phenomena, enabling still photographs to be taken with any type of ordinary stand camera.

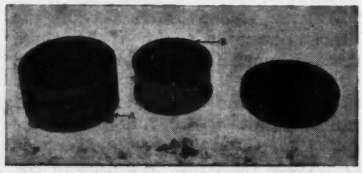
(*b*) Slow non-cyclic phenomena, for which a moving film or paper is required.

(*c*) Cyclic phenomena, where each cycle is not necessarily an exact repetition, and

(*d*) Transients.

For these various types of work a number of different types of tube are available, which can again be roughly subdivided into four groups, namely :

(*a*) Low voltage gas focused, with anode voltages, up to about 1,000, having screens giving green, blue or a reddish radiation, the latter having a very long time persistence. With these tubes, records can successfully be made of most of the types of trace listed under (*a*), (*b*) or (*c*) previously described, provided that the frequency is not above about 5,000 c/s. As, however, the brilliancy is inherently low due to the low anode voltage, it is necessary to use a fast orthochromatic or panchromatic film to obtain useful records of the higher frequencies.



The long persistence screen giving the reddish radiation is primarily of use where the rate of change of the phenomenon under investigation is very slow. Since a persistence of some ten seconds can be obtained, it enables the trace to be visualised as a trace and not just a spot travelling slowly over the screen. Photography of the residual image is also possible, although it usually gives a rather diffused result.

(*b*) Medium voltage high vacuum tubes, with anode voltages from 500 to 2,000 volts. These are available with the same screens, but owing to the higher voltages employed, much more brilliant spots can be obtained, and consequently faster phenomena can be photographed, and there is less defocusing at high speeds. The majority of commercial oscillographs at the present time employ high vacuum tubes of this type on account of the much greater photographic efficiency

* Messrs. Rotax, Ltd.

and also because tubes of this type are more stable than gas-focused tubes. There is, however, the disadvantage that they necessarily require a bigger work voltage for a given deflection than a gas-focused tube, thereby involving the use of amplifiers.

Here I propose to digress very briefly to mention a point which, though not strictly within the scope of this paper, has nevertheless provided a definite problem in our laboratories.

The use of amplifiers by, say, mechanical engineers has invoked grave doubts in their minds as to the reliability of all records when they have once realised that in certain cases the characteristics of the amplifier may modify the wave shape observed. This problem has led us to install a six-element Duddell type oscillograph for use within the lower frequency range, and there are many instances where its simplicity, and freedom from pick-up of stray radiations, are of great advantage under workshop or test-bed conditions.

(*c*) High voltage tubes above 2,000 volts. These are usually supplied with screens giving a blue or bluish white fluorescence, and under suitable conditions can be used even for the recording of high-speed transients mentioned in (*d*) before.

This application is dealt with in Mr. Nethercot's paper* and will not be elaborated here.

(*d*) The continuously exhausted oscillograph with the plate inside the vacuum chamber. This is used where the very highest writing speeds are required, the action being by direct electron bombardment of the photographic emulsion.

This is not strictly a photographic problem, since the light sensitivity of the emulsion does not enter into the question. It is, however, advantageous to use a thin emulsion for two reasons. Firstly, to avoid unnecessary de-gassing in the vacuum, and secondly, to prevent spreading of the image in the thickness of the emulsion.

For the same reason, plates are preferable to films since the plasticisers in the film base are extracted in the vacuum and vapours are very troublesome.

With these various tubes three types of camera may be used, such as the ordinary plate or film camera, giving single exposures of stationary traces, the continuous film camera, usually employing 35 mm. cinematograph film, which can be run either continuously or one frame at a time, and the drum type with a synchronous shutter or beam trigger arrangement, to provide exposure during one revolution of the drum only.

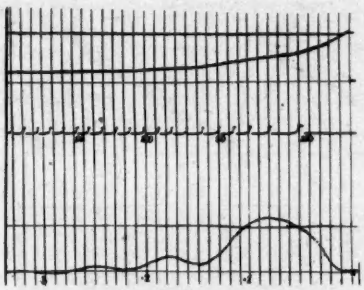


Fig. 2. Record obtained from camera of Fig. 1, with three double-beam tubes.

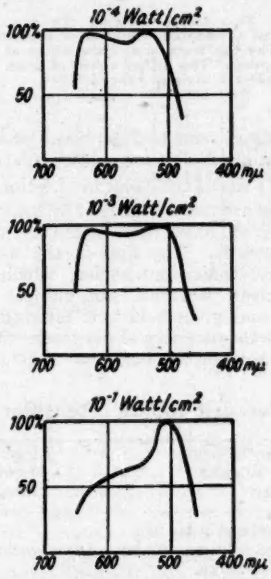



Fig. 3. Showing how the screen spectral emission changes with beam current. (after von Ardenne)

Such a camera made in our own laboratory is shown in Fig. 1. The drum has a peripheral length of 10 inches and the maximum speed is 6,000 r.p.m., giving a film speed of approximately 80 ft./sec.

An extension of the second type usually employs wide paper material where multiple recording is required of traces from 3, 4 or 6 tubes simultaneously.

Fig. 2 shows part of a typical record obtained with such a camera where three double beam tubes are employed. The parallel vertical lines are time marks spaced 1/100 in. apart. This being done by means of a lamp shining through a slotted disk attached to a small synchronous motor, and focused on the moving paper through a cylindrical lens.

This has two advantages: It is possible to view the screen at the back of the camera and align all the spots on the image of the slit before taking the record, and the line being printed photographically at the time of exposure there is no need to worry about mechanical distortion of the paper during processing which is often quite appreciable. It also reveals any variation in the speed of the paper drive.

For the majority of work the single-shot process is not of very great application and recourse must usually be had to some form of continuous film or paper camera with the addition of a drum-type camera where specially high resolution is required in the time axis. The recording materials used may be paper, film or plates. These are obtainable in a variety of sizes and speeds and sensitised for all colours, with the exception of the paper which, so far as I know, is not obtainable in the panchromatic form.

The choice of a suitable material for any given application is dependent upon the speed of the phenomenon under investigation, the brilliancy of the spot, which is a function of the working voltage of the tube, the aperture and transmission efficiency of the photographic lens; and the spectral colour of the emission of the material forming the fluorescent screen.

A blue fluorescent material is normally recommended for photography by the makers of the tubes, and for this reason it is often argued that only a blue sensitive emulsion is required. In practice, however, it is often found that an orthochromatic or panchromatic emulsion will give greater rapidity. The reason for this appears to be that although the screen may appear wholly blue, there is actually an appreciable amount of green radiation present simultaneously. An interesting point is that the spectral emission of a screen may change with changing beam current. This is shown in Fig. 3, taken from *Cathode Ray Tubes* by Von Ardenne.* It will be seen that up to 1 milliwatt/sq. cm. the radiation for this particular screen tends to be in the yellow and red region, whereas at 100 milliwatts/sq.cm. the radiation is concentrated in the green.

The implication is that in the first case a panchromatic emulsion would give the best results, whereas at the higher intensity an orthochromatic emulsion would do all that is required.

Quite small changes in the setting of the brilliancy control often make large

* Publication to follow.—Ed.

* Pitman & Sons

differences in the apparent recording sensitivity; probably due to this effect. For most purposes a fast orthochromatic emulsion will be found adequate and is preferable to the use of a panchromatic emulsion, with its attendant disadvantage of having to work in the dark, or at least, in a very much reduced amount of illumination.

Where a screen giving the green fluorescence is utilised, it is essential to use either an orthochromatic or panchromatic emulsion, and care should be taken to see that the image is not blurred by after-glow in the screen. Many green screens have an appreciable after-glow, this being intended to assist visual examination of the trace. The writer has taken a photograph five seconds after the apparent traces had vanished from the screen, and obtained a double image which puzzled him until the reason was found in the persistence of glow mentioned above.

For many purposes, particularly where the reproduction of the records is unnecessary, or where the very highest recording speeds are not required, recording paper can be utilised instead of film. This gives a very nice trace and is considerably cheaper, particularly in large widths, say, up to 6 in., or when the record may stretch to several feet in length.

**Processing**

With regard to development, any good clean-acting metolhydroquinone developer will serve for the majority of work, but where maximum contrast is required one of the developers especially recommended by the makers of the material should be tried, such as Kodak D19B or Ilford ID33.

Where there are marked changes in velocity of the traces over different parts of the record, causing a very faint image where the spot is travelling fast, and a heavily over-exposed image where the spot is slow or stationary, the writer has a preference for developing very rapidly in a concentrated developer, so as to develop only the surface of the emulsion, followed by intensification (if necessary) to increase the density of the image so developed, the idea behind this being that where the spot is travelling slowly the image will spread in the depth of the emulsion. If only the surface be developed the exposed grains lying deeper in the emulsion are not affected, and hence in the over-exposed parts, the apparent width of the line is reduced. At the same time, where the image is faint, due to the high speed at which the spot is travelling, the emulsion will only be exposed on the surface in any case, therefore development restricted to the surface will not have a deleterious effect. Once having obtained

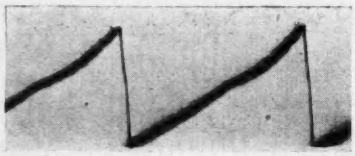


**Fig. 4. Two traces showing the effect of restricted development with after intensification. The top trace shows the effect of full development. The higher speed of trace has lost a little in reproduction.**

the image it can be intensified by any one of a number of suitable methods.

Fig. 4 shows the effect in question.

There are two methods of intensification which have been found to give good results. The first is the usual mercuric iodide intensifier, which is very clean working, not subject to stains and gives sufficient intensification for the majority of purposes. The formula is shown below :—

### Mercuric Iodide Intensifier

| | |
|---|---|
| Mercuric Iodide ... ... | 2.5 gm. |
| Sod. Sulphite ... ... | 50 gm. |
| Water ... ... ... | 250 c.c |

Dissolve sulphite first
Mixed solution will keep a few weeks in the dark.

The second method, which can give very great intensification, was recently described in the *British Journal of Photography*. The formula is :—

### Silver Intensifier

| | | |
|---|---|---|
| 1 | A Uranium Nitrate ... | 1 gm. |
| | Glacial Acetic ... ... | 12.5 cc. |
| | Water ... ... ... | 100 cc. |
| | B Pot. Ferricyanide ... | 1 gm. |
| | Water ... ... ... | 100 cc. |
| | Take 1 part of A and 2 parts of B | |
| 2 | Wash film thoroughly in running water | |
| 3 | Bleach in : | |
| | Silver Nitrate ... ... | 0.3 gm. |
| | Nitric Acid ... ... | 0.5 cc. |
| | Water ... ... ... | 100 cc. |
| 4 | Rinse in distilled water acidified with a few drops of nitric acid | |
| 5 | Bath in 4 per cent. Sod. Bromide until no further change is seen (about 2—4 mins.) | |
| | Re-develop in any standard developer (MQ) | |

**Fig. 5. A useful method of recording with economy in film where the form of the transient is not important but where it is required to check a sequence of operations.** *(Here again the reproduction does not do justice to the original record, which is remarkably clear-cut.—Ed.).*

It is considered that each application of this intensifier will give an increase in density of five times. The only disadvantage of this method is that it takes some little time to operate, since extreme cleanliness of every dish is essential, and the use of distilled water is also essential if one is to avoid the most disastrous and immovable stains appearing all over the image.

It has just been found that not all film will respond to treatment with this intensifier. The reason for this is not yet apparent, but where it can be used the effects are excellent.

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## Sola Constant Voltage Transformers

In an article on "Voltage Regulating Transformers" by R. O. Lambert, which appeared in our issue of February, 1943, mention was made of a constant voltage transformer under the heading "Non-saturated Cores."

Messrs. Sola Electric Co., of Clybourn Avenue, Chicago, have written to point out that this transformer was developed and patented by them* and is fully described in their illustrated catalogue.

We regret that by an oversight the source of the information in the article was not acknowledged and are grateful to Messrs. Sola Electric for drawing our attention to the omission.

* U.S. Patents 2143745 and 1893251.

# Communication at Supersonic Frequencies

**A summary of an article by S. J. Weitzer, which appeared in the October, 1943, issue of Q.S.T. The practical suggestions given will be of great interest to radio experimenters who would like something new to investigate at the present time. They are reminded, however, of the restrictions in force on the use of power valves and transmitting apparatus.**

THE use of inaudible sound as a means of communication has been neglected, but it provides a fresh and highly interesting field for research. Several years ago the writer undertook some development work and this article describes some of his experiences. These will be dealt with qualitatively, with the intention of providing a background for the experimenter.

It should be understood that air is a poor conductor of high-frequency sound; the higher the frequency, the greater is the absorption. For this reason, an uneconomical amount of power is required to project high-frequency sound for any great distance in air. In other words greater amplitudes of vibration are required for propagation in air, and this places a decidedly greater strain on the vibrator. At 10,000 c/s, for a certain amplitude at the source, sound will travel almost 2,000 times farther in water than it will in air. Sound also can be sent along wires for a considerable distance.

Several types of high-frequency sound generators, in the order of their importance, are quartz crystals, magnetostriction vibrators, air jets or special whistles, loud-speakers of the condenser and tweeter types, and the spark gap.

The generation of sound waves of frequencies up to 400,000 c/s is common practice in supersonic laboratories; in fact, frequencies of several million cycles have been produced by advanced workers in this field. Most of the research work dealing with these frequencies utilises quartz crystals as the sound generators. In order to obtain high-intensity sound, a crystal cut to the desired frequency is driven by a power oscillator. As is well known, r.f. crystals excited by more than 10 or 20 watts will be damaged. In supersonic generators the crystals generally are immersed in oil or other liquid for mechanical damping and cooling, but even so there is a limit to the energy which can be applied to the crystal. For extremely high-power work, several crystals are connected in parallel. Crystals for 20 kc/s to 50 kc/s are large bars or slabs, and at these frequencies do not possess much activity; for a given driving power, they cannot vibrate as vigorously as crystals cut for higher radio frequencies. If the vibration amplitude becomes too large, the crystal literally tears itself to pieces. However, some investigators have driven crystals with as much as 3 kilowatts of power.

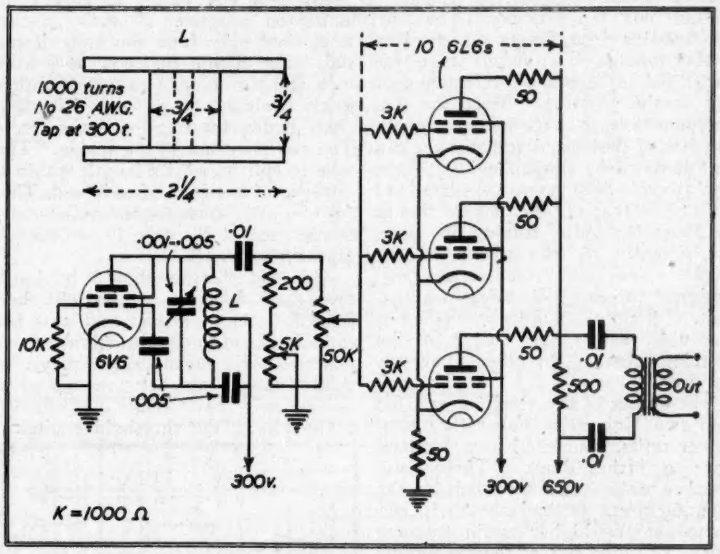



**Fig. 1. Supersonic oscillator and amplifier. The output stage is ten parallel 6L6's (only three of which are shown).**

Since the velocity of sound in quartz is close to the velocity in steel, a thin section of quartz can be cemented between two thicker steel plates and the whole will resonate like a single plate of the same total thickness, the over-all thickness determining the frequency. A unit with a thickness of 2½ inches will resonate at about 35,000 c/s. This arrangement not only has the advantage of cheapness, but—more important—greater amplitudes of sound can be obtained for the same exciting voltage.

The initial urge to take up an investigation of supersonics came about as the result of a desire on the part of the water engineers and health officials of a certain coastal city to rid their water reservoirs of seagulls. It happens that, during high tide, the gulls fly over the reservoir and drop their excrement into the water. Of all refuse there is nothing so foul as the excrement of a sea gull, and it may endanger the health of persons regularly drinking such water.

Since it is known that many birds and insects have hearing organisms sensitive into the supersonic range, it was considered that a powerful high-frequency sound with a wobbulated effect might give the birds a disagreeable sensation and tend to drive them out of range of the sound, while being, at the same time, inaudible to the local residents. In practice, this was proved to be the case. Although no permanent installation was made, demonstrations at the reservoir and the waterfront gave quite a jolt to all the winged fowl within a quarter mile; they fluttered and squeaked and quickly took themselves off to more peaceful parts. In the course of the writer's experiments parrots and canaries became so terrified that they flapped around in their cages in a frenzy, their feathers flying in all directions. Canaries afterwards acted sick and depressed, and it took several days for them to return to normal. Flies behaved differently; seemingly they became stupefied, and could be picked off the walls with the fingers.

Most of these tests were made at threshold frequencies. (The author's ears being good to 18,000 c/s, no special detector was necessary. Detectors for high-frequency sound will be discussed further on.) The equipment consisted of a simple low-power oscillator feeding a special a.f. amplifier designed for reasonable efficiency

at high frequencies. The latter was an output stage with ten 6L6s in parallel, single-ended, for the purpose of providing a low-impedance load and thus minimising distributed-capacity effects in the output transformer. (*See* Fig. 1.) The output transformer was sectionalised, with the secondary wound over the primary. The core consisted of iron filings packed into rubber tubing. The output stage was shunt fed to keep the d.c. component out of the winding. Since the d.c. component is as much as 0.5 ampere, the size of the output transformer can be cut down by shunt feeding. There is a 250-volt drop across the plate load resistor so that the d.c. source should be about 650 volts, leaving 400 volts d.c. actually on the plates of the 6L6s. The power transformer was designed for this job, being a ½-kva. unit. A 1.0-μF. 2,000-volt condenser was used across the output of the rectifier tubes. No other filter was required.

The output of the amplifier was fed into two University Laboratory p.m. driver units, connected to a common horn 9 inches long. These loudspeaker units were modified by the manufacturers to increase their efficiency at the higher audio frequencies. The diameter of the diaphragm was made smaller and the suspension stiffer, and the entire mass of the moving elements was reduced. Thus the units actually became high-power, high-efficiency tweeters.

With the loudspeaker installed on a fire-escape and pointed down the street the pitch at 16 kc/s could be heard over one-third of a mile before being lost finally in the surrounding street noises. This pitch was inaudible to most persons; only an occasional passer-by seemed to "sense" its presence.

Contrary to expectation, the attenuation or absorption in air does not seem to be as great as mathematical computation for this frequency would indicate. There is very little change in the observed sound level whether one is 200 feet or 1,000 feet away. Reflexion from buildings is very marked and all sense of direction of the source of the sound is soon lost. However, when projected in free, open space the sound has a fairly narrow projection angle.

### Magnetostriction Vibrators

In an effort to obtain greater sound intensities, a magnetostriction vibrator was built up somewhat as illustrated in Fig. 2. The same amplifier was used, except that the output transformer was replaced by a winding on the core of the magnetostriction vibrator. In this case, the d.c. plate supply of 400 volts goes through this winding to provide magnetic polarisation of the magnetostrictive rod. This "rod" actually is monel metal tubing, of varying diameters and lengths, fitted with flanged aluminium end plates to permit its acting on a greater air area. Sound is emitted only from the ends of the rod. The flange diameter is ¾ to 1 inch and the flanged section is rather thick (½ inch) to prevent distortion from nodes forming on its surface. The rod must act like a piston. The tube is split down its length within a distance of one inch of each end. This reduces eddy currents because the circumference of the tube is broken for most of its length.

The end flanges should be hard force-fitted into the tubing and then pinned. Small screws and nuts become loosened under the vibration, no matter how much they may be tightened. Rods between 6 and 7 inches long have their fundamental frequency in the threshold region.

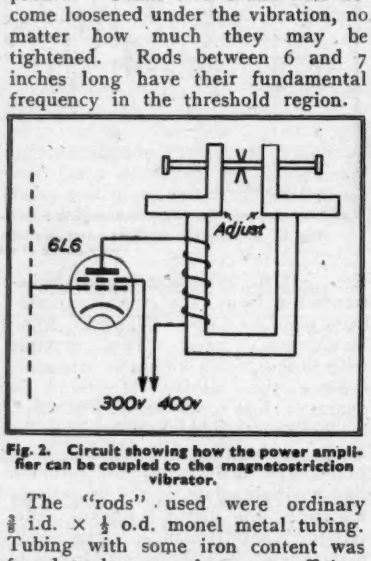



**Fig. 2. Circuit showing how the power amplifier can be coupled to the magnetostriction vibrator.**

The "rods" used were ordinary ⅜ i.d. × ½ o.d. monel metal tubing. Tubing with some iron content was found to be somewhat more efficient than the tubing without it.

A high-power self-oscillator was built up using two 204-A tubes in parallel. The plate coil was wound over one leg of the magnetostriction core. This oscillator was capable of delivering powers up to 500 watts and had a tuning range of from 7,000 to 30,000 c/s, using a bank of fixed condensers for tuning. At 16,000 c/s the range was over two miles. The equipment could be maintained in operation only for a scant two or three minutes, however, because by that time the rod and other solid iron parts became hot.

There is much room for improvement in the design of the magnetostriction vibrator. According to one investigator, the maximum practical amplitude of vibration of the rod is one ten-thousandth part of its length. At higher frequencies, where harmonic vibration is utilised, the amplitude is much smaller and the sound intensity correspondingly weaker. Reduction of core losses would reduce heat and provide the same amplitude with less expenditure of energy. Any improvements in this direction would represent an important contribution to this science.

The physical dimensions of the magnetostriction rod are not too small for the average constructor to fabricate and handle. At a fundamental of 20 kc. the length is between 4½ and 5 inches. It is not possible to give the exact length, because it varies with rods of different chemical composition. Monel metal is composed of 68 per cent. nickel and 28 per cent. copper, together with small amounts of iron, silicon, manganese and carbon. Other nickel alloys, such as Invar (36 per cent. Ni, 64 per cent. Fe), cobalt and nichrome, are good vibrators.

### A Supersonic Detector

A simple detector for supersonics in the region of 20 kc/s can be made from an old ribbon microphone. The ribbon is removed and the corrugations smoothed out. It is then cut down to a width of ¼ inch. The end-supports for the ribbon at the top and bottom of the magnet are used to support light extension plates, so that the total length of unsupported ribbon is reduced to ¾ inch. The ribbon is mounted between these new supports. There should be no wrinkles in the ribbon and it should be stretched as tight as possible.

The microphone output is fed into a well-shielded voltage amplifier, made up of three pentode stages. Careful construction technique must be employed, or the amplifier will be unstable and may develop self-oscillation at some supersonic frequency. This must be eliminated by good design practice, rather than by capacity-shunt effects or high-frequency attenuation as would be permissible in amplifiers designed only for audio frequencies.

The author recommends a book entitled "Ultra-Sonics," by L. Bergmann, published by John Wiley & Sons, New York. This book includes one of the most complete bibliographies on this subject.

The *Journal of the Acoustical Society of America*, Vol. 9, No. 3 (January, 1938), contains several articles and the *Review of Modern Physics*, Vol. 11, No. 1 (January, 1939), contains a bibliography of over 300 references.

# DATA SHEET 57

## Aerial Characteristics—V

## Radiation Resistance and Effective Height.

### Radiation Resistance

IN last month's Data Sheet the effect of ground losses on the loss resistance of a grounded aerial was treated by an approximate method which is reasonably accurate at medium frequencies. Ground losses, however, also affect the radiation resistance of an aerial.

Two papers have dealt with the effect of finite ground constants on the resistance of an aerial The first of these papers[1] gives a method for calculating the complex input impedance of a half-wave vertical dipole above a ground having arbitrary constants. The method is generally applicable in practice down to a wavelength of the order of 10 metres. The second paper[2] gives an accurate method of calculating the radiation resistance of different types of aerial above a ground of arbitrary characteristics.

Table I gives figures taken from the latter paper on the effect of ground conductivity on the radiation resistance of a grounded quarter-wave aerial and a half-wave horizontal dipole a half wavelength above ground.

Fig. 1 illustrates the effect of finite ground constants on the radiation resistance of a vertical and horizontal half-wave dipole at different heights above ground. The solid curves are calculated for perfect ground while the points denote measurements made at wavelengths between 8 and 27 metres. The measurements were carried out over a salt marsh and an average ground (Holmdel N.J.) having a conductivity of $1.3 \times 10^{-13}$ e.m.u. or $1.3 \times 10^{-4}$ mhos/cm[3]. Both from the theoretical and practical point of view the radiation resistance of a vertical half-wave aerial is little affected by the finite conductivity of average soil at short wavelength. With a horizontal dipole, while the effect is greater, it is still small provided the height is greater than about 0.2 of a wavelength. The input resistance of horizontal aerials suspended at a height of less than 0.2 wavelengths depends considerably on both the wavelength and ground constants.

From Table I it will be seen that the radiation resistance of a quarter-wave grounded aerial is very materially affected by the constants of the ground. (The figures in Table I are calculated to an accuracy of only about 1 per cent.)

**TABLE I.**

| Type of Aerial | Ground Characteristics as specified by $K'$ $K'=K+jq$ | Calculated Loop Radiation Resistance $R_L$ ohms. |
|---|---|---|
| Grounded quarterwave vertical aerial | 1 | 19.4 |
| | 7 | 16.8 |
| | 7+j | 16.3 |
| | 7+j10 | 16.8 |
| | 7+j100 | 23.8 |
| | 7+j ∞ | 36.5 |
| Half wave Horizontal dipole one half wavelength above ground | 1 | 72.7 |
| | 7 | 69.7 |
| | 7+j | 69.2 |
| | 7+j10 | 66.7 |
| | 7+j100 | 67.0 |
| | 7+j ∞ | 70.3 |

*After Hansen and Beckerley, Proc. I.R.E., December, 1936.*

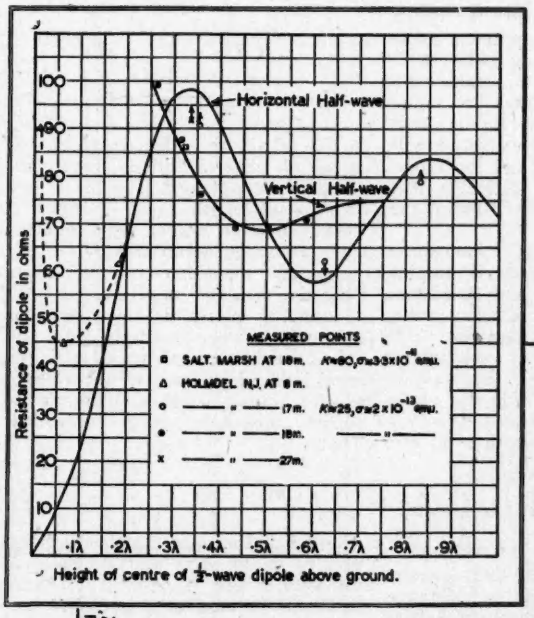
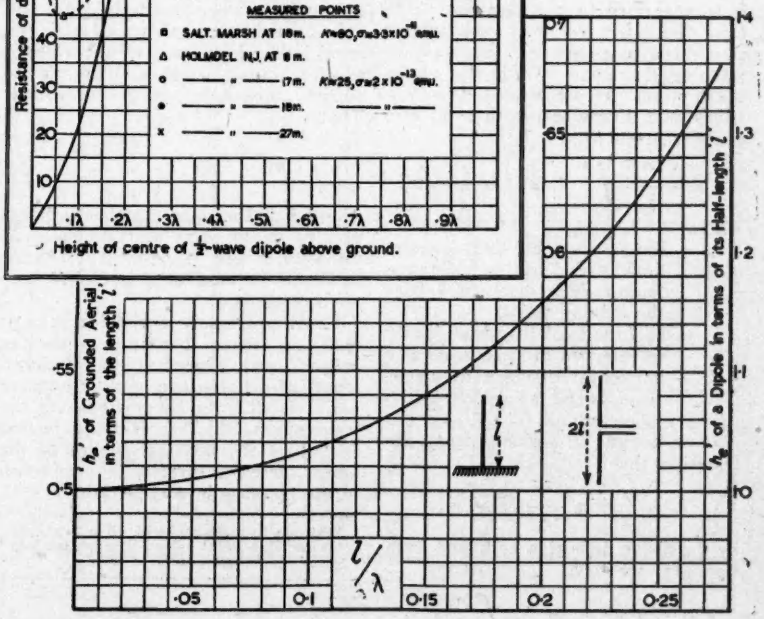

Horizontal Half-wave
Vertical Half-wave
Resistance of dipole in ohms
MEASURED POINTS
SALT MARSH AT 18m. K=80, σ=3·3×10⁻¹³ emu.
HOLMDEL N.J. AT 8m.
17m. K=25, σ=2×10⁻¹³ emu.
18m.
27m.
·1λ ·2λ ·3λ ·4λ ·5λ ·6λ ·7λ ·8λ ·9λ
Height of centre of ½-wave dipole above ground.

**Fig. 1 (left). Effect of ground constants on radiation resistance of grounded ¼-wav aerial and ½-wave horizontal dipole.**

*After Friis, Feldman & Sharpless Proc. I.R.E., 1943.*

**Fig. 2 (below). Effective height of short dipoles and grounded aerials in terms of their physical length.**

*(Calculated from Eqns. 48 & 49)*



# Effective Height

While the term " Effective height," $h_e$, is not often used in the case of transmitting aerials, it is, however, often referred to in books, especially when an aerial is employed for reception. It may be defined as follows:

The "effective height," $h_e$, is the length of elemental aerial (*see* Fig. 4, Part II, Oct. issue) which, when placed in the same position as the actual aerial and carrying a uniform current $I$, will produce the same field strength as that radiated by the actual aerial, with a current equal to $I$ flowing at some stated reference point.

In practice the most convenient reference current to use is the current $I_e$ at the point where the aerial is energised,* and this definition will therefore be employed in this series of Data Sheets. In a general definition of "effective height" a further qualification must be provided which specifies the angle of elevation for which the stated value of $h_e$ applies. As in this article we are dealing mainly with aerials whose length is small compared with a wavelength, the maximum radiation both for the elemental and actual aerial in free space will occur with $(\theta)_v = 90°$ and the radiation in the horizontal direction will therefore be assumed in defining the effective height.

As the field in the immediate vicinity of a radiator is very complex including the static and induction terms as well as the radiation terms, it is necessary to compare the fields, from the reference and actual aerial at a distance of not less than, say, 5 wavelengths away. With the above assumptions the radiation field intensity $e$ of a dipole of length $2l$ in free space is given by

$$e = \frac{120\pi}{\lambda d}\int_0^l I_y\, dy \text{ volts/metre} \quad \ldots\ldots (46)$$

where

$I_y$ = r.m.s. current in amperes flowing through an elemental length $dy$ a distance $y$ from the driving point.
$l$ = half the total length of dipole.
$\lambda$ = wavelength in same units as $l$.
$d$ = horizontal distance in metres from aerial at which field $e$ is measured.

If we assume sinusoidal current distribution then

$$I_e = I_L \sin\frac{2\pi}{\lambda}(l - y),$$

by the above definition and from equation (13) we have

$$h_e I_e = h_e I_L \sin G = 2\int_0^l I \sin\frac{2\pi}{\lambda}(l - y)\, dy \quad \ldots\ldots (47)$$

therefore

$$h_e = \frac{\lambda}{\pi}\frac{1 - \cos G}{\sin G} = \frac{\lambda}{\pi}\tan\left(\frac{\pi l}{\lambda}\right) = l\frac{\tan(G/2)}{G/2} \quad \ldots\ldots (48)$$

Thus the effective height of a doublet whose length is short compared with a wavelength is equal to half its overall physical length. For values of $l \leqslant \lambda/12$ this is true in an accuracy of better than 2%.

For a half wave dipole $h_e = \lambda/\pi$ and $I_e = I_L$

The case of grounded aerials of length $l \leqslant \lambda/4$ over perfect ground can be treated in a similar way and

$$h_e = \frac{\lambda}{2\pi}\tan\left(\frac{\pi l}{\lambda}\right) = l/2\frac{\tan(G/2)}{G/2} \quad \ldots\ldots (49)$$

so that again the effective height of an aerial whose length is short compared to a wavelength is equal to half its physical length.

The effective height of a quarter wave grounded aerial is $\lambda/2\pi$.

Another definition of the term "effective height," applicable only to a receiving aerial, is the length of wire which when multiplied by the existing field strength would give the same induced or open circuit voltage as the actual aerial delivers at its output terminals when unloaded. That is

$$h_e = \frac{E}{e} \quad \ldots\ldots (50)$$

where $E$ is the open circuit e.m.f. expressed in the same units as the field intensity $e$ and is equal to $I_e R_B$ or $I_L R_L$ in the case of a perfectly conducting ground.

From previously derived results it will be seen that the "effective height" and therefore the induced e.m.f. of a half-wave or quarter-wave aerial is directly proportional to the wavelength, this result is to be expected as the physical length of the aerial increases directly in proportion to the increase in wavelength.

*This applies to shorter aerials up to $l = \lambda/4$. In the case of grounded half-wave aerials the loop current $I_L$ must be used.

In practice $h_e$ in equation (50) is usually given for the orientation of the wire giving maximum response, when the field intensity $e$ does not lie along the wire only the component of $e$ along the wire must be employed.

### Metre-amperes

From equation (46) the field strength in free space for a given length and distance $d$ is only proportional to $\int_0^l I_y dy$. Now we can write a general relation applicable also to grounded aerials over perfect ground:

$$I_e h_e = \int_0^l I_y dy \quad \ldots\ldots (51)$$

(The factor of 2 in equation (47) comes from the purely arbitrary definition that the overall length of a dipole is equal to $2l$ while the overall length of a grounded aerial is equal to $l$.)

The product of the terms on either side of equation (51) is usually known by the term "Metre-amperes" of an aerial, a term that has had considerable use by transmitting engineers. While at first sight it appears to be a very convenient criterion for comparing short aerials, the previously described effects of finite ground conductivity on directivity and losses made its use under practical conditions rather limited, especially as one is usually more concerned with the field strength obtainable for a given power input. It can, however, be employed for comparing the field strength from different aerials on a given site. These remarks apply equally to the "effective height" $h_e$, under practical conditions, will depend on the ground constants and ground system.


REFERENCES.

1 "On the Impedance of a Vertical Half-Wave antenna above an earth of Finite Conductivity" by W. L. Barrow, Proc.I.R.E. Feb. 1935.
2 "Concerning new methods of Calculating Radiation Resistance either with or without ground" by W. W. Hansen & J. G. Beckerley, Proc. I.R.E. Dec. 1936.


## Corrections to Data Sheet 56

Equation (39) should read:

$$\frac{I_g}{I_w} \approx j\frac{120}{\lambda}\sigma\left[\frac{x}{n}\right]^2\left\{\log_e\frac{\pi}{a}\left(\frac{x}{n}\right) - 0.5\right\}$$

In equation (44) read $S$ for $s$. Equation (45) should read:

$$S = \frac{\lambda}{2\pi\sqrt{\frac{\sigma}{f}\left(\frac{K^2f^2}{4\sigma^2} + 1\right)^{\frac{1}{2}} - \frac{K}{2}}}$$

# DATA SHEET 58—Conical Aerials

IN the first part of this series (Data Sheet 51, September issue) formulae were given for the calculations of the reactance of short conical aerials. The radiation resistance was, however, neglected.

In an outstanding article S. A. Schelkunoff ("*Theory of Antennas of Arbitrary Size and Shape*" *Proc. I.R.E., Sept.*, 1941) deals in detail with the theory and performance of biconical aerials, and some of the information given in this article is reproduced here.

As in the following performance curves of conical aerials, the relative cross-sectional dimensions of the aerial are expressed in terms of the Characteristic Impedance $Z_o$, where

$$Z_o = 120 \log_e (\cot \frac{\phi}{2}) \text{ ohms}$$

Fig. 3 has been prepared to facilitate the evaluation of $Z_o$ in terms of the cone apex angle ($2\phi$), for angles between 0.02° and 20°.

Fig. 4 illustrates the manner in which both the radiation resistance and reactance of a hollow biconical aerial (without end caps) in free space vary with its length, the length being expressed in terms of $2\pi l/\lambda$. The reactance and resistance represent the components of the impedance at the input terminals of the aerial, the solid curves depicting the resistance component while the dotted curves depict the reactive component. The figures by the curves represent the value of $Z_o$ for each curve the + sign representing the zone of inductive reactance and the − sign representing the zone capacitative reactance.

Fig. 5 illustrates the variation of the input resistance with length (*i.e.*, $l/\lambda$) plotted on semi-logarithmic paper for a range of $Z_o$ from 600-1,200 ohms.

Fig. 6 shows similar curves for the input reactance for a range of $Z_o$ from 500-1,200 ohms.

For a given cone angle the input resistance reactance and characteristic impedance of a vertical grounded hollow conical aerial over a perfect ground, may be obtained from these curves by halving the values of $Z_o$, the input resistance and input reactance given for the bi-conical case. Thus, for example, a hollow biconical aerial of length $l \approx \lambda/2$ having a $Z_o$ = 1,000 ohms has an input resistance (radiation) of 5,000 ohms. If half this aerial is used as a vertical grounded inverted cone, then over perfect ground $Z_o$ will be 500 ohms and the input resistance will be 2,500 ohms; similarly the input reactance will be halved.

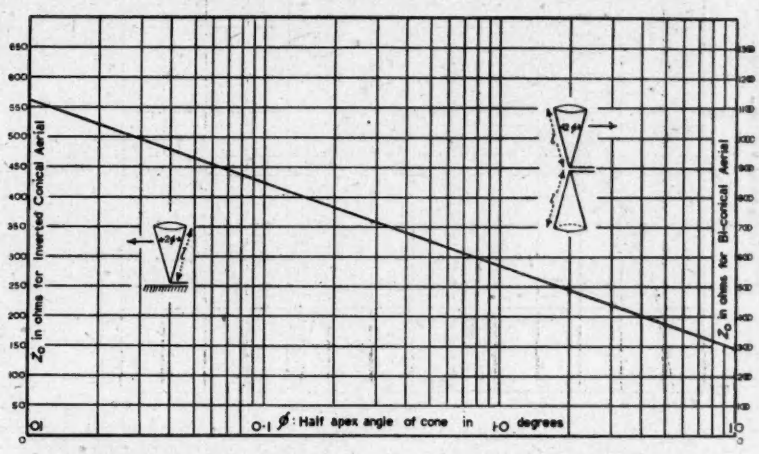
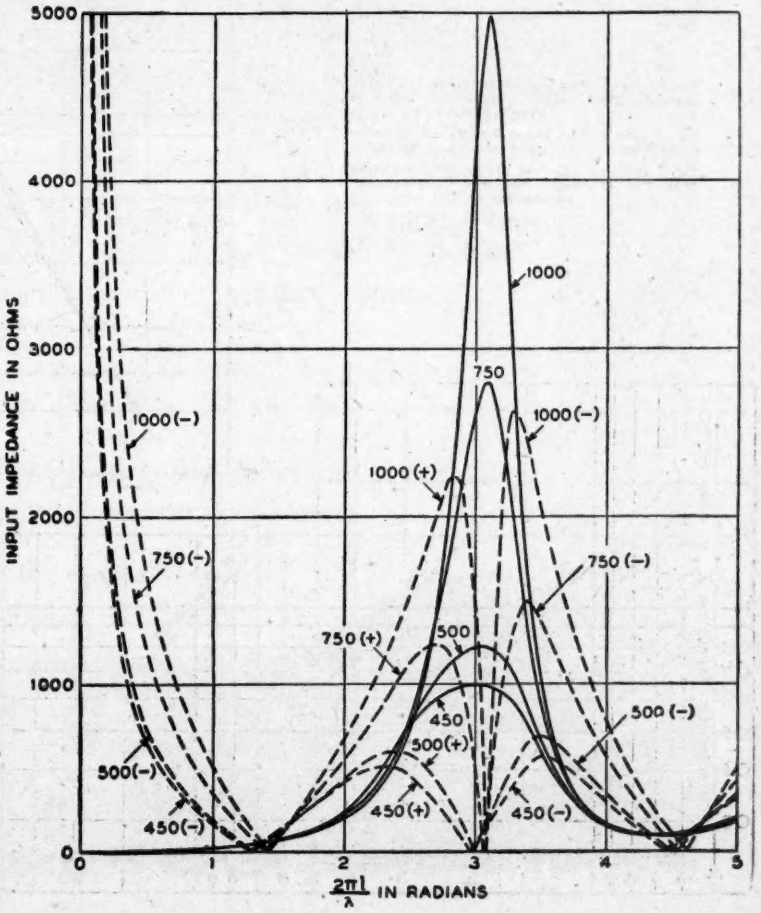
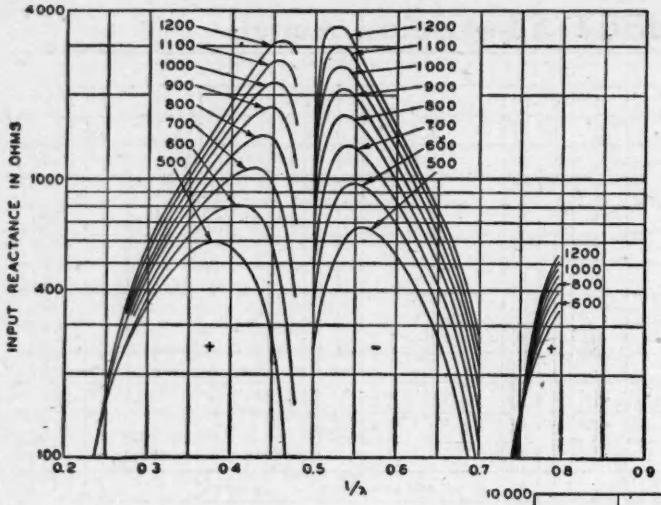



**Fig. 3 (above). Variation of characteristic impedance $Z_o$ with the cone apex angle.**
**Fig. 4 (below). Input impedance of hollow conical aerials (without spherical end-caps) as a function of $2\pi l/\lambda$ and $Z_o$. Solid curves are the real component and dotted curves the imaginary component.** *(From Schelkunoff, Proc. I.R.E.).*





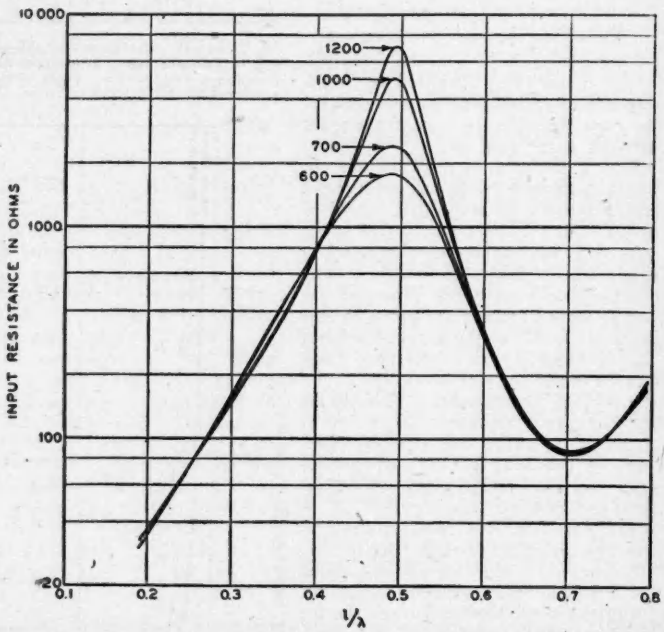
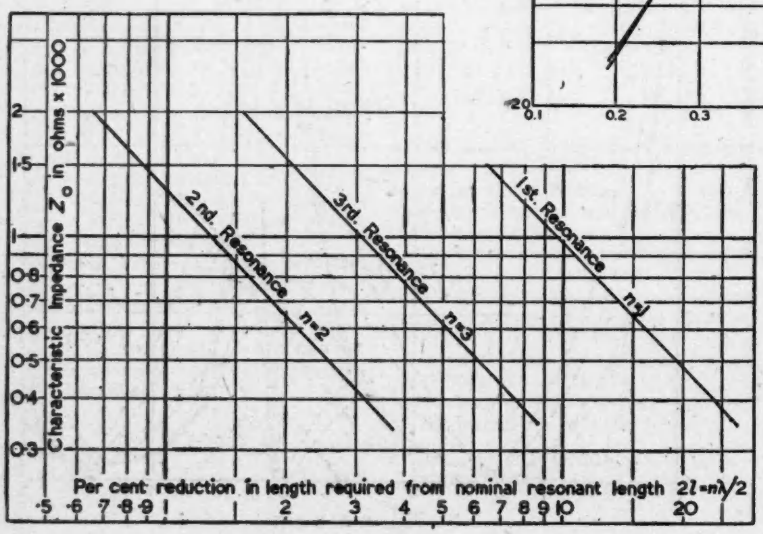




**Fig. 5 (right). The Input Resistance of a hollow conical aerial (without spherical end-caps).** *(From Schelkunoff, Proc. I.R.E.).*

**Fig. 6 (top). The Input Reactance of hollow conical aerials.** *(From Schelkunoff, Proc. I.R.E.).*

**Fig. 7 (below). Curves giving the percentage reduction in length required to resonate a conical aerial.**

*(After Schelkunoff Proc. I.R.E.)*




From the curves on Fig. 6 it will be seen that with an aerial of finite dimensions, when $l = \lambda/2$ (*i.e.*, the second resonance for an infinitely thin zone), the reactance is not zero and the aerial has to be made shorter in order to make the reactance equal to zero. In Fig. 7 are given curves from which it is possible to read off the percentage shortening required for a hollow conical aerial (without end caps) operating at the first, second, and third resonance points, *i.e.*, $l \approx \frac{1}{4}\lambda$, $l \approx \frac{1}{2}\lambda$, and $l \approx 3\lambda/2$. Thus for a half wave (first resonance) biconical aerial $2l \approx \lambda/2$ and $Z_0 =$ 1,000 ohms. The shortening is approximately $9\frac{1}{2}\%$, and therefore to obtain zero reactance, $2l = 0.452\lambda$.

As the cross-sectional dimensions of the aerial are reduced and $Z_0$ becomes larger and larger so the shortening effect becomes smaller.

Apart from being amenable to calculation the main advantage of conical aerials is their suitability for use in wide pass-band applications such as television. By the use of large angle cones, which give a low value of $Z_0$, the variation of reactance with frequency is reduced. This considerably simplifies the efficient coupling of the aerial to the transmission line.

For further information on conical aerials the reader is referred to the original article quoted above.

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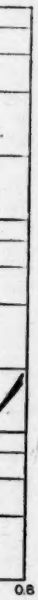


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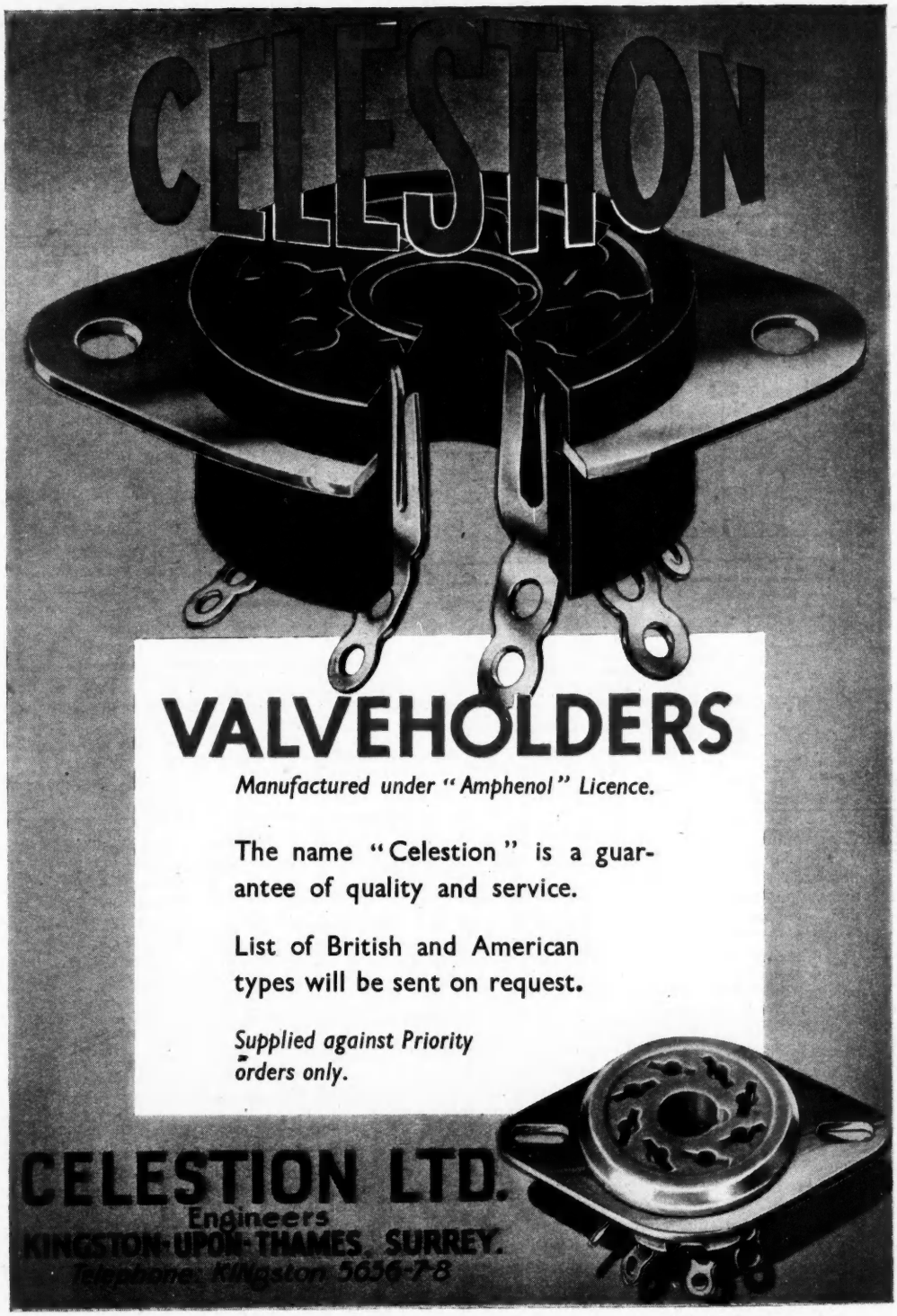


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# A Photo-Electrically Operated Stop-Watch

By R. J. WEY, A.M.I.E.E.

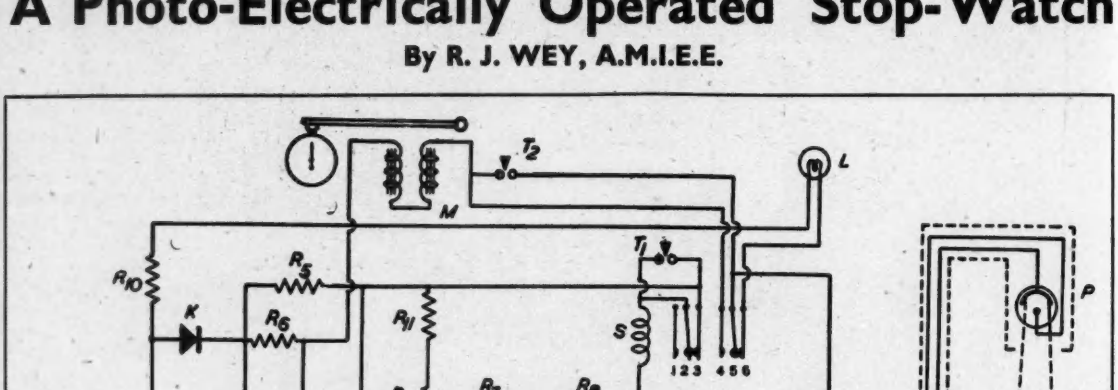


**Fig. 1. Circuit diagram for operating with double occultation.**

**Component Values.**

| | | | | |
|---|---|---|---|---|
| $R_1$ 5 meg. | $R_6$ 0.25 meg. | $C_1$ 0.05 μF (mica). | K HT. 16 rectifier. | S P.O Relay 10,000 ohms. |
| $R_2$ 10 meg. | $R_7$ 0.10 meg. | $C_2$ 4.0 μF. | P Gas-filled photo-cell. | $T_1$, $T_2$ Relay re-setting buttons. |
| $R_3$ 2,000 ohms. | $R_8$ 0.25 meg. | $C_3$ 4.0 μF. | L 230 v. 15 w. lamp. | V MH. 4 or equivalent. |
| $R_4$ 10,000 ohms. | $R_9$ 0.25 meg. | $C_4$ 12.0 μF (paper). | M Electromagnet. | Q 12 v. 24 w. Car lamp. |
| $R_5$ 15,000 ohms. | $R_{10}$ 1,200 ohms. | $C_5$ 1.0 μF. | | |
| | $R_{11}$ 5,000 ohms. | $C_6$ 1.0 μF. | | |

THERE are many instances in industry or the laboratory, in which it is necessary to measure accurately the time taken for the performance of a given operation, or the completion of a process. When the time to be measured is of the order of a day, visual observation of a good timepiece is sufficient to give excellent accuracy (better than .01%), and when the time is of the order of one hour, visual observation may again suffice, although the use of a stop-clock is desirable. No skill on the part of the observer is required in these cases, but when the time to be measured is of the order of one minute or less, matters are not so simple, and careful observation and rapid reactions are essential if the most accurate results are to be obtained from the stop-watch, which is normally used for such measurements. Of course, the stop-watch itself will possess errors, although these are unlikely to be greater than 0.2 second and in many cases are considerably less.

The additional errors due to the human element (observation and reaction times), can be eliminated entirely by electro-magnetic operation of the stop-watch. It is necessary in this method, to cause a contact to be closed at the beginning and end of the cycle of operations being timed, thus closing the circuit of an electro-magnetically operated stop-watch. Naturally, the use of the contacts must not interfere physically with the operation being performed, and since in many instances, this is not possible, the photo-electric method must be employed. This method may be used in all cases in which the start and finish of the operation or process can cause interruption or modulation of a light beam. For instance, the light beam may be interrupted momentarily at both the start and finish of the cycle, or the beam may be interrupted for the duration of the cycle. In order to reduce to the minimum any small errors which might result from the use of a relay associated with the photo-cell amplifier, the first mode of operation is preferable, since the relay operates in the same sense for both the start and finish of the cycle. The time delays are thus more likely to be equal and hence cancel each other, than if the relay operated in one sense at the start and in the opposite sense at the finish, which is normally the case when the second mode of operation is used.

A photo-electric timing device of this nature was constructed some years ago for laboratory use, and it has proved itself to be so reliable and convenient that it is thought that a description would be of interest.

## Circuit

Referring to Fig. 1, it will be seen that the photo-cell *P* is coupled by means of the resistance $R_1$ and condenser $C_1$ to the grid of the triode valve *V*. In the anode circuit of the valve is a telephone type moving iron relay *S*, wound to a resistance of about 10,000 ohms. Six contacts are

provided, giving the equivalent of a double-pole double-throw switch, and the operating current of the relay is adjustable by means of a spring tension device acting on the armature. When anode current is passing, the contacts numbered *2* and *5* are deflected to the right, closing the circuits through contacts *3* and *6* respectively. A small indicator lamp *L*, operated via contacts *5* and *6*, shows that the relay armature is pulled in and that the apparatus is in an operative condition. The potentiometer $R_3$ allows the grid bias of the valve to be adjusted so that the anode current is sufficient to cause positive operation of the relay (3.5 to 4 mA. was found to be a suitable value).

The anode potential of the photo-cell is adjusted by means of the potentiometer $R_4$, and the photo-cell itself is provided with a suitable earthed housing and screened connexions to the amplifier. A rectifier *K*, delivering about 350 volts D.C. supplies anode current to the valve and photo-cell through a resistance $R_5$, which, in conjunction with the condenser $C_2$, provides sufficient smoothing.

Normally, the photo-cell is illuminated so that the point *X* is at a positive potential with respect to the cathode of the valve *V*. When the light beam is interrupted, the potential of point *X* drops to practically zero, causing the grid potential to fall to a low value. The anode current thus falls, releasing the relay armature. The effect of this is threefold:

(1) Contacts *4* and *5* close the circuit to the stop-watch electro-magnet *M*.
(2) Contacts *5* and *6* open, so that the indicator lamp *L* is no longer illuminated.
(3) Contacts *2* and *3* open the anode circuit of the valve *V*.

Thus the watch has commenced the timing, whilst the amplifier is rendered inoperative, *i.e.*, will not respond to illumination and occultation of the photo-cell, whether accidental or otherwise. Before the finish of the cycle of operations being timed, it is thus necessary to reset the apparatus by means of the push-button $T_1$, which allows anode current to pass and pull in the relay armature. The first occultation of the photo-cell after this has been done will cause energisation of the stop-watch electro-magnet, completing the timing operation.

A standard type of stop-watch is used, operated by means of a powerful electro-magnet and armature acting upon the start and stop knob. The first impulse causes the watch to start, the second to stop, and a third, given by means of the push-button $T_3$ after the reading has been taken, causes the watch to be reset to zero ready for the next cycle of operations.

It has been customary in the past to use a 12 volt accumulator to energise the stop-watch electro-magnet, but in the present arrangement, the inconvenience of this has been avoided by utilising the anode supply. Referring to the diagram, it will be seen that the condenser $C_4$ is charged to about 350 volts by the rectifier through the high resistance $R_6$, and that closure of the relay contacts *4* and *5* causes the condenser to discharge through the stop-watch electro-magnet *M*.

The advantages of this method are:

(a) The rectifier load is increased by only 1.4 mA. upon operation of the stop-watch, although the electro-magnet may require 50 mA. for energisation.
(b) More rapid operation can be obtained since a momentary discharge of many times the normal current may be passed through the coils without danger of overheating.

### Stop Watch Details

The mechanism described here can be used with any standard type of stop-watch, it being simply necessary to arrange a suitable mounting to accommodate the watch case. Referring to Fig. 2, it will be seen that the watch *A* is mounted in a recess cut in a block of wood *B*, a felt lining being provided to give a snug fit and prevent damage to the watch. A brass plate *C* clamps the watch in position, and should it be required for other purposes, the watch may readily be removed by undoing the milled heads *D*. It need not be removed from the mounting block, however, for winding.

The electro-magnet coils *E* and *F* are approximately 3.25 inches long by 1.5 inches diameter, and are each wound with about 12,000 turns of No. 36 S.W.G. Enam. copper wire. It is preferable to wind in layers, insulating each layer with a layer of oiled paper, and applying shellac varnish to each layer of wire during winding.

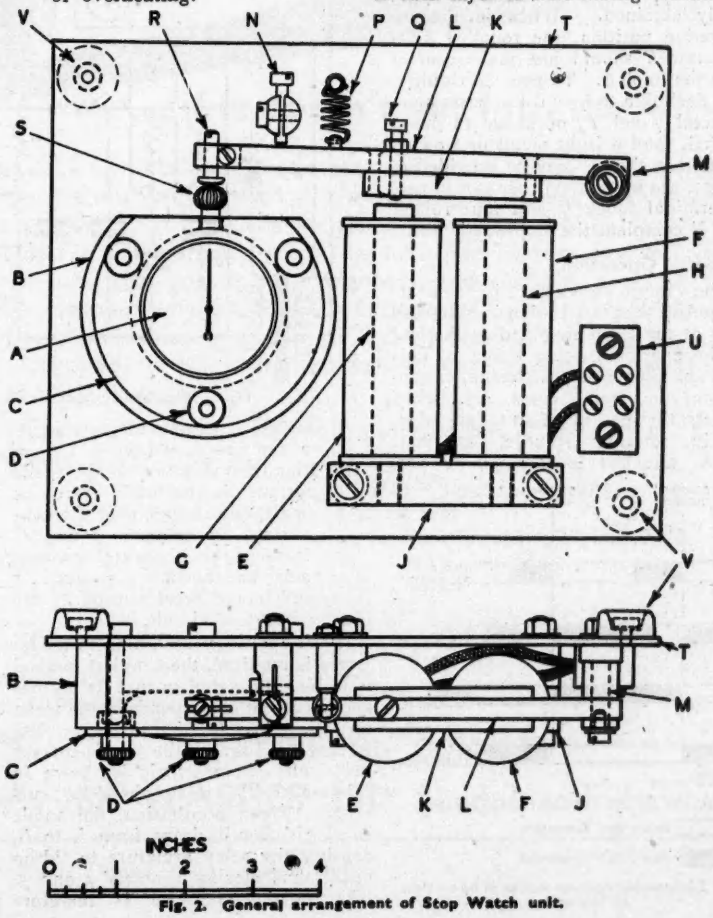


Fig. 2. General arrangement of Stop Watch unit.

The coils are finished off with 2 layers of Empire cloth.

The magnet cores *G* and *H* are of annealed soft iron, $\frac{5}{8}$" diameter, screwed into a stout yoke *J* of similar material. The armature *K* is also of annealed soft iron, $\frac{5}{8}$" × $\frac{3}{8}$" in section, and is attached rigidly to the brass operating arm *L*, of 5/16" × 5/16" section. A suitable pivot is provided at *M*, positioned with respect to the magnet cores to give an air gap of about .02" when the armature is parallel with the pole faces.

The screw *N* forms an adjustable back stop, against which the arm *L* is held by means of the spring *P*. A brass screw *Q* projects through the armature, and is adjusted so that the armature is not retained by residual magnetism when the coils are de-energised. It should be noted that this screw must make contact with the pole face before the knob of the stop-watch has been depressed to its limit, otherwise a very considerable force will be brought to bear upon this. Normally, this adjustment is quite easily obtained. When in the in-operative position, the rounded head of screw *R* should just make contact with the knob *S*. To provide rigidity, it is desirable to mount the parts upon a metal panel *T*, of about 12 or 14 S.W.G., and a light metal or wooden cover (not shown) may be provided to protect the apparatus when not in use. A terminal block *U* and four rubber feet *V* complete the stop-watch unit.

### Modes of Operation

The circuit shown in Fig. 1 is arranged so that occultation is necessary both at the beginning and at the end of the operation being timed. This may not always be practicable, or convenient in many cases, *e.g.*, when timing the period of rotation of a slowly rotating spindle, a small mirror attached to the spindle provides a very simple means of modulating the light beam, resulting in a short flash of light upon the photo-cell at the beginning and end of the period. Four modes of operation are illustrated in Fig. 3, which is self explanatory.

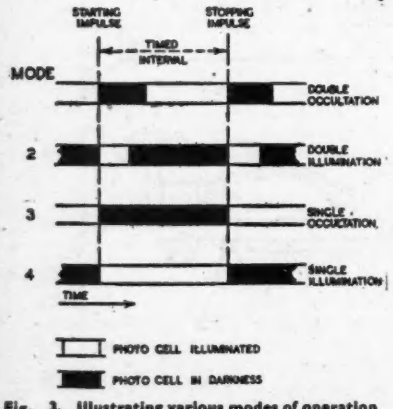


Fig. 3. Illustrating various modes of operation of the unit.

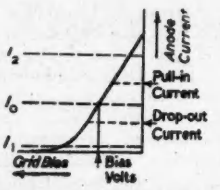


Fig. 4. Operating points on the valve characteristic.

Since operation according to mode 1 is obtained with the circuit as described, to obtain operation according to mode 2, the following modifications should be made:

(a) Reverse the position of the photo-cell and coupling resistance $R_1$, leaving the relay connexions as shown, or

(b) Bias the valve so that the anode current is normally zero or small, and change over the connexions to contacts *4* and *6*, leaving the photo-cell connexions as shown. Contact *1*, *2* and *3* and reset button $T_1$ are cut out of circuit.

When operation according to modes 3 or 4 is required, the simplest method is to bias the valve so that its normal anode current corresponds to the mean operating current of the relay. Referring to Fig. 4, the anode-current grid volts characteristic is shown in relation to the relay operating currents. Upon occultation, the anode current suddenly drops from $I_0$ to $I_1$, causing the relay armature to "drop out," thus closing contacts *4* and *5*. The starting impulse is therefore given to the stop-watch from condenser $C_1$ (*see* simplified circuit diagram shown in Fig. 5.) The photo-cell still being darkened, the anode current will rise (relatively slowly, at a speed determined by the time constant of the coupling $R_1$, $R_2$, $C_1$) to the original value $I_0$, but owing to the differential in the operating currents of the relay, the armature will not "pull in." Illumination of the photo-cell at the completion of the cycle causes the anode current to rise to $I_2$, thus pulling in the armature and closing contacts *5* and *6*. The "stopping" impulse is therefore given to the stop-watch from condenser $C_8$.

After a short interval, the anode current again returns to its original value $I_0$, but the relay armature is not released. The apparatus is then ready to operate upon a further occultation of the light beam. Since an impulse is given for alternate occultations and illuminations, the same circuit will operate according to modes 3 or 4, it being merely necessary to ensure that the relay is in the correct condition at the beginning of the cycle. Two indicator lamps $L_1$ and $L_2$ operated via relay contacts *1*, *2* and *3*, serve to indicate the position of the relay, and may be marked to show whether illumination or occultation is required to cause the next impulse to be given to the stop-watch.

Owing to the use of the two condensers $C_1$ and $C_8$, resetting of the stop-watch to zero is preferably performed by depressing the operating arm by hand. The use of two reset push-buttons is thus avoided.

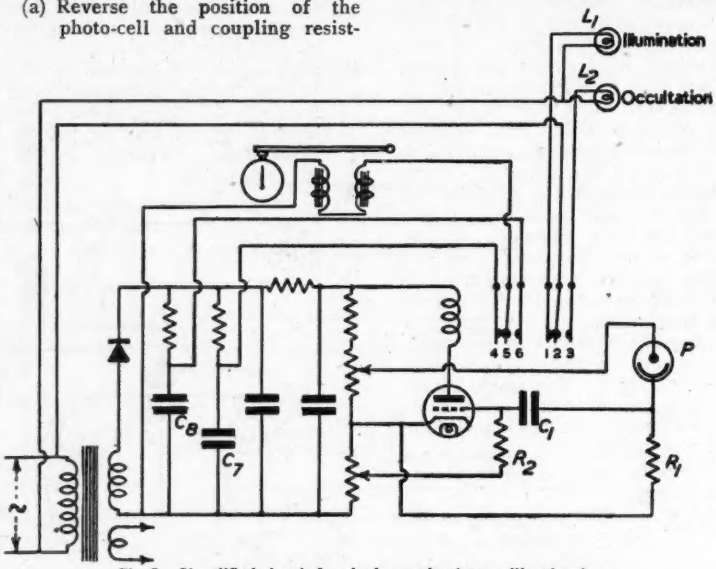


Fig. 5. Simplified circuit for single occultation or illumination.

## . . . if it doesn't get into the wire"

Anyone who lays cables will tell you that water can be the Very Devil. It works its way into where it's not wanted with all the cunning of a quisling. Whether as a flood or a trickle, it is always a menace. Now, BX P.V.C. (Polyvinyl Chloride), like Noah in Chesterton's poem, has no use for water. It says "Keep out" and means it—and that goes for oils, alcohols, and sunlight, too. So you can see one of the reasons* why BX P.V.C. Extrusion Compound is preferred for cable coverings, radio insulating sleevings, etc. It extrudes with great ease and uniformity; supplied in black and colours in four grades of flexibility. Working samples with pleasure.

**Here are some of the other reasons. This data concerns* **BX P.V.C.** *in the form of Extrusion Compound.*

| | |
|---|---|
| **Specific Gravity** | 1·35—1·5 Black and colours; 1·20 Natural |
| **Tensile Strength** | up to 9000 lbs. depending on grade |
| **Elongation at Break** | up to 500% depending on grade |
| **Softening Range** | 90°—100°C. |
| **S.I.R.** | $2{\cdot}46\times10^{13}$ |
| **S.I.C.** | 8·62 |
| **Power Factor** | 12·5% |
| **Breakdown Voltage Kv/cm.** | 550 |
| **Retains flexibility without cracking down to** | —20°C. |

**bx P.V.C.** EXTRUSION COMPOUND

**BX PLASTICS LTD. London and elsewhere**

LUND HUMPHRIES BX191

# High Frequency Therapy

## Part V.—Energy Absorption in Biological Media

by W. D. OLIPHANT, B.Sc., F.Inst.P.*

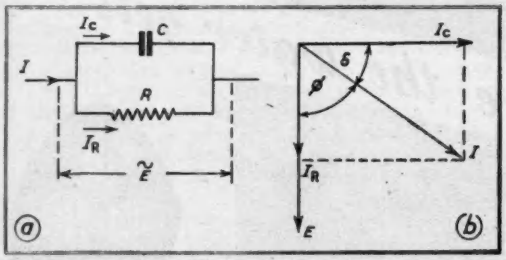


Fig. 1.

WE shall now consider the optimum conditions for the production of heat in a biological material when placed in the condenser field. For the moment we will assume that the material completely occupies the space between the electrodes and that it creates an equivalent circuit as shown in Fig. 1a, wherein we have a capacitance $C$ shunted by a resistance $R$. The relevant vector diagram is shown in Fig. 1b.

The effective value of the applied alternating potential difference $E$ creates a current $I$ which divides, as shown, into two components $I_r$ and $I_c$. The loss angle ($\delta$) and the phase angle ($\phi$) are also shown.

The quantity of heat produced is proportional to the power loss multiplied by the time, thus

$$Q = J^{-1}P.t$$
$$= J^{-1}E.I.\cos\phi.t$$
$$= \frac{I^2Rt}{J.(1 + C^2R^2\omega^2)} \quad \ldots\ldots\ldots (1)$$

where Q = heat produced in calories;
$J$ ≙ Joule's equivalent.

Maintaining $I$, $t$, $C$ and $\omega$ constant but varying $R$ we get for a maximum heat quantity $Q_{max}$ that $R$ must be equal to $1/\omega C$. In other words, the maximum condition calls for a phase angle of 45°, and so

$$Q_{max} = \frac{1}{2J} . I^2.R.t \quad \ldots\ldots\ldots (2)$$

Now let $\sigma$ and $\epsilon$ be the specific conductivity and dielectric constant respectively, both being expressed in E.S.U. Let also $l$ be the thickness of the medium between the electrodes and $A$ be the cross-sectional area.

Then $R = \frac{l}{\sigma.A}$ and $C = \frac{\epsilon.A}{4\pi l}$

hence from the optimum relation $R = 1/C\omega$ we get

$$\frac{l}{\sigma.A} = \frac{4\pi l}{\omega.\epsilon.A}$$

and so $\sigma = \frac{\epsilon.f}{2}$ ..... (3)

where $f$ is the frequency in cycles/sec.

This is the fundamental optimum relation connecting conductivity, dielectric constant and frequency, and it enables us for a given material to calculate readily that frequency which will ensure maximum heat production in a given time and for a given current as read on the output meter of a therapy machine.

Equation (2) could have been otherwise derived from equation (6) of part II since, as $\delta = 45°$, tan. $\delta = 1$.

In practice it is convenient to work in terms of wavelength and in the practical electrical units, thus if

$\lambda_{cm}$ = wavelength in cm. $= 3 \times 10^{10}/f$
$\sigma$ = conductance in ohm$^{-1}$ cm.$^{-1}$
(1 E.S.U. of conductance $= 9 \times 10^{11}$ ohm$^{-1}$ cm.$^{-1}$)

then equation (3) can be written

$$\sigma = \frac{\epsilon}{60.\lambda_{cm.}} \text{ ohm}^{-1}\text{ cm.}^{-1} \quad \ldots (4)$$

We have seen how it is advantageous to work in practice with air separation between the electrodes and the body and it is now necessary to extend the theory to embrace this case. Consider the condenser arrangement in Fig. 2 (a).

In this case a glass cell contains the biological solution, and, as before, the effective length and cross-sectional area are respectively $l$ and $A$. The electrodes are distant $d$ apart and it is assumed that the resulting field is homogenous and that all dielectric boundary surfaces are in equipotential planes. The equivalent circuit is shown in Fig. 2(b) where $C_a$, $C_a'$ and $C_g$, $C_g'$ represent respectively the condensers afforded by the air gaps and the glass cell walls; these are grouped together as $C_1$ and $C_2$. The condenser $C_3$ represents the shunt capacitance arising from the electrodes themselves and may be termed a leakage capacitance. The various current components are clearly shown in the diagram.

It can be shown that

$$I_1^2 = \frac{I^2[R^2C^2\omega^2 + 1]}{C_3^2[S^2 + R^2\omega^2(1 + SC)^2]}$$

where $S = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

Now $I_{1r}^2 = \frac{I_1^2}{R^2C^2\omega^2 + 1}$, hence

$$I_{1r}^2 = \frac{I^2}{R^2\omega^2[C_3 + S.C.C_3]^2 + S^2C_3^2}$$

and so

$$Q = J.^{-1}I_{1r}^2\,Rt = \frac{J.^{-1}I^2Rt}{R^2\omega^2[C_3 + S.C.C_3]^2 + S^2C_3^2} \quad \ldots\ldots (5)$$

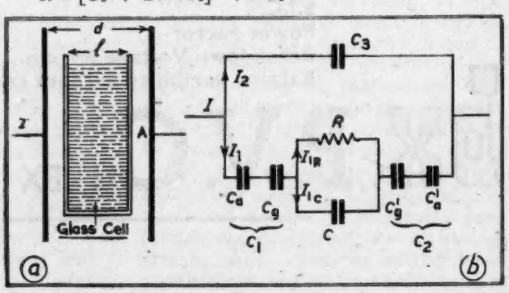


Fig. 2.

* University of St. Andrews.

Callender

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CALLENDER'S CABLE & CONSTRUCTION CO. LTD. HAMILTON HOUSE, VICTORIA EMBANKMENT, LONDON, E.C.4

*All over the World*

The value of $R$ for constant $\omega$, $C$, and $t$ and for $Q_{max}$ is given by

$$R_{max} = \frac{S}{\omega(1+SC)}$$

and so on introducing $\sigma$ and $\epsilon$ as before, we finally obtain the new optimum condition given by

$$\sigma = \frac{\epsilon.f}{2}\left\{1 + \frac{4\pi l}{S.A.\epsilon}\right\} \quad \ldots\ldots\ldots\ldots (6)$$

This is similar to equation (3) except for the term $\left\{1 + \frac{4\pi l}{S.A.\epsilon}\right\}$ which takes account of the air gaps and the glass cell. These two expressions become more and more equal as $\frac{4\pi l}{S.A.\epsilon}$ approaches zero.

Now the ratio $\frac{l}{A\epsilon}$ is fixed and so it would be necessary to have $S \rightarrow \infty$ that is for

$$\left\{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right\} \rightarrow \infty$$

Again, $C_1$ and $C_2$ cannot be altered and so we have the final unavoidable condition that $C_3$ must tend to zero. In other words, we must arrange to have the leakage capacitance as small as possible by employing suitable sized electrodes.

In the foregoing we have established the fundamental theoretical conditions which are necessary in order that maximum advantage may be made in treatment with a given machine.

### The Conductivity of Electrolytes

In dealing with solid conductors of a given material it is possible to employ the familiar specific conductance or conductivity, but when we pass on to deal with electrolytic or conducting solutions, the conductance does not so much depend on the actual material between the electrodes as on the number of ions formed by the solute. In other words we must take into account the concentration of the solution and compare solutions of *equivalent* concentration. This gives rise to the quantity *equivalent conductivity* ($\lambda$) which is defined as the conductance of a solution which contains 1 gram-equivalent of the solute when inserted between two electrodes of indefinite size set 1 cm. apart. In general, the equivalent conductivity is related to the specific conductance ($\sigma$) by the relation

$$\lambda = \sigma.\phi$$

where $\phi$ is the volume of cm³ in which 1 gm. equivalent of the electrolyte is dissolved.

If $C$ represents the number of gram-equivalents in solution, then we also have that

$$\lambda = \frac{\sigma}{C}$$

In certain literature the term *molecular* (*or molar*) *conductivity* is used. By this is meant the conductivity of a solution containing 1 gram-molecule of electrolyte when placed between two electrodes of indefinite size set 1 cm. apart. It is equal to the specific conductivity multiplied by the volume in cm³. which contains 1 mole of the dissolved substance.

The equivalent conductivity increases with dilution and tends towards a maximum. The maximum value is termed the equivalent conductivity at infinite dilution ($\lambda\ \infty$). In ionic conduction each ion plays its part and it follows that the equivalent conductivity at infinite dilution must be equal to the sum of the two ionic conductivities, the one depending on the cation and the other on the anion. This is due to the fact that at infinite dilution the solution is completely ionised. This is known as the law of the independent migration of ions and stated in symbols, where $l_c$ and $l_a$ represent the ionic conductivities due to cation and anion respectively, we have

$$\lambda\ \infty = l_c + l_a$$

Ionic conductivity increases with temperature rise in accordance with the familiar general thermal equation,

$$l_t = l_{18}\left\{1 + \alpha\,(t - 18)\right\}$$

The temperature coefficient $\alpha$ for ions of normal mobility is of the order of 0.024, getting less as the mobility increases. Values for ionic conductivity are usually given for 18° C., and so the above equation is stated with respect to that temperature. It thus follows that the equivalent conductivity increases with rise in temperature, but the variation is a complex one, and its actual measurement is further complicated by the attendant change in the dielectric constant of the solution.

The degree of electrolytic dissociation is expressed by Arrhenius's coefficient which is the ratio of the conductivity at infinite dilution (that is to say, when dissociation is complete) to the equivalent conductivity at a dilution of 1 gram-equivalent in the given number of litres. This is true for weak, but not for strong electrolytes.

In ionic separation we require to expend a certain amount of work in overcoming the attractive force between the two opposite charges, and since this force is inversely proportional to the dielectric constant of the medium, it follows that ionisation will be more complete, other things being equal, in a medium of higher dielectric constant. Thus an aqueous solution of a salt may be completely ionised, while if the salt is dissolved in another solvent of lower dielectric constant it will not be the case. In the latter case ionic doublets may exist.

Substances are generally graded in terms of their conductivity and come under the headings of electrolytes (including practically all salts and strong acids and bases); half-electrolytes (such as weak acids and bases) and non-electrolytes (such as sugar and urea), but there is no sharp line of demarcation.

When an electrolyte is subjected to a static electric field we get a continuous migration of ions to the electrodes giving rise to the phenomenon of electrolysis. When, however, the electric field is an alternating one, electrolysis cannot take place, and so no chemical change is brought about. The conductivity is further dependent on the frequency of the field to which the electrolyte is subjected. Within the electrolyte we may conceive an ionic cloud which is maintained by the mutual attractions and repulsions of all the ions. On applying an electric field this cloud will undergo a change in its general structure and a finite time will be necessary for this change to come about. This relaxation time which is more concisely defined as the time required for the moments of the molecules to revert to random distribution after removal of the applied field, is given by the relation

$$\tau = \frac{8.85 \times 10^{-11}.\epsilon}{\lambda_{\infty}.Z.\upsilon}$$

where

$\tau$ = relaxation time in seconds;
$\epsilon$ = dielectric constant;
$\lambda_{\infty}$ = conductivity for infinite dilution;
$Z$ = electrochemical equivalent, and
$\upsilon$ = molecular concentration.

The effect of the electric field on the ionic cloud is to produce asymmetry in the charge distribution with ultimate diminution in the ionic mobility. As the frequency increases this asymmetry becomes less and less with consequent increase in conductivity, and so at the highest frequencies the conductivity is such as to be unaffected by internal electrostatic forces.

### Electrical Phenomena in Colloidal Solutions

Matter is said to exist in the colloidal state when its degree of subdivision lies between that which is readily observable by means of a microscope and the molecular state; the magnitude being of the order of from $10^{-7}$ to $10^{-6}$ cm. A colloidal solution or sol is heterogeneous and it is a system in which the particles are distributed in a dispersed phase in a continuous dispersion medium. When the material particles are solid we refer to them as suspensoid colloids or suspensoids, and their stability in solution is due to their motion and to the presence of electric charges. The second group of colloidal sols containing emulsoids possess greater viscosity and lower surface tension than water. The dispersion medium in this case is adsorbed by the colloid and stability is more dependent on adsorption than on electric charges. Dispersion media may be gaseous, solid or liquid, but it is the last case which is of most interest here.

When a solid particle becomes suspended in a liquid medium of higher dielectric constant it becomes, in general, negatively charged relative to the dispersion medium and will therefore be attracted to the anode of an electrode system placed in the solution. This phenomenon is known as cataphoresis and is completely analogous to electrolysis in the case of an electrolyte. In cataphoresis we speak of the degree of dispersion, electric density of the surface charge and the electric potential of the double layer, while in electrolysis we speak of concentration and the degree of dissociation. The theory of the conductivity of colloidal solutions is extremely involved though it is logical to regard electrolytic conduction as the limiting case of cataphoretic conduction.

Turning now to the question of the dielectric constant of a colloidal solution we are faced with the question as to whether or not it is different to that of the dispersion medium, bearing in mind the fact that the dielectric constant of the dispersed phase is in general considerably different to that of the dispersion medium.

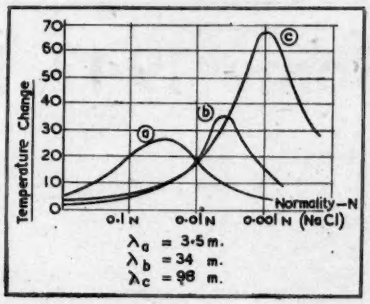



**Fig. 3.**

Millikan studied the case of an emulsion of water in a mixture of benzene and chloroform, regarding the water droplets as conductors suspended in an insulator and he found that he could apply the Clausius-Mosotti formula, thus

$$\epsilon = \epsilon' \cdot \frac{1 + 2x}{1 - x}$$

where $\epsilon$ = dielectric constant of the emulsion;
$\epsilon'$ = dielectric constant of the dispersion medium;
$x$ = ratio between the volume of the dispersed phase and the total volume.

The above is the case for a non-aqueous dispersion medium. For an aqueous dispersion medium the dielectric constant of the colloidal solution was found to agree with that of the water. The above conditions hold only for slightly solvated solutions. In the case of highly solvated solutions, on the other hand, the dielectric constant usually differs very considerably from that of the pure dispersion medium.

### Experimental Evidence of Selective Heating Effect

Experiments have readily proved that selective heating effect takes place as a function of wavelength and when several dielectric materials are simultaneously traversed by the electric field, it is found that alteration of the wavelength or frequency of the field brings about very marked changes not only in the individual temperatures in the media, but also in their relative temperatures. The selective heating effects are particularly marked in the case of experimental models made up with electrolytic and colloidal solutions, but they are less marked in the case of actual body tissues and organs. It has been demonstrated that minute material particles situated within a medium of an entirely different dielectric constant may be selectively heated. This was most markedly demonstrated by Esau who subjected an emulsion of a hydrated electrolyte and oil to a high frequency field. The electrolyte was violently expelled from the oil showing that its boiling point had been reached while the oil was yet relatively cool. Again, Schliephake showed how red blood corpuscles are raised to a higher temperature than the blood serum. This so-called point heating effect has been held responsible for the bactericidal effect of a high frequency field.

The selective heating of electrolytic solutions is shown very clearly in Fig. 3, which is the case for a common salt solution of varying concentration. As can be seen, as the conductivity increases so also must the frequency to ensure optimum heat production. The concentration is here plotted logarithmically and is given in terms of solution normality.

In conclusion, Holzer and Weissenberg, in their book, give a table showing the optimum wavelengths in relation to thermal energy absorption for various biological materials. These figures have been derived from equation (4) taking a constant value of 85 for the dielectric constant.

*(To be continued.)*

**TABLE** *(from Holzer & Weissenberg)*

| Material | $\rho$ ohm cm. | $\lambda$ m. |
|---|---|---|
| Ascites fluid (dog) ... | 113 | 1.6 |
| Blood (dog) ... ... | 219 | 3.1 |
| Kidney (dog) ... ... | 345 | 4.9 |
| Cartilage and sinew (dog) | 385 | 5.6 |
| Nerve (ox) ... ... | 481 | 6.0 |
| Muscle (striped-dog) ... | 500 | 7.0 |
| Pus (dog) ... ... | 521 | 7.4 |
| Spleen (dog) ... ... | 769 | 10.9 |
| Liver (dog) ... ... | 1500 | 22.0 |
| Bone (dog) ... ... | 1920 | 27.2 |
| Skin (guinea pig) ... | 11000 | 156.0 |
| Distilled water ... ... | 100000 | 1410 |

# Some 1943 Products

**Some of the products illustrated in this review are only available for priority orders, but in all cases the manufacturers will be pleased to give further particulars to industrial firms and engineers who are interested.**

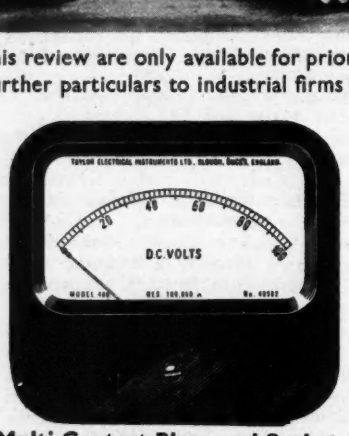
## New Taylor Moving Coil Instruments

Ten types of moving coil instruments are available from 2 to 5 inch scales. Models 400 and 500 have 4 inch and 5 inch scales respectively, and employ a robust movement with Alnico magnets and stainless iron polepieces and core. By the use of Alnico magnets, extremely high magnetic fields are achieved making it possible to use higher control torque than usual and also to construct quite robust instruments consuming 20 mA or less full scale.

These can be supplied with either knife edge or spade pointers, mirror scales and illuminated dials. Both models are of the rectangular pattern and are housed in black moulded cases. Instruments are normally well damped, but partially damped or undamped instruments can be supplied to order. Rectifier and thermo-couple instruments are also available covering a wide range of accurate measurements.

Moving coil voltmeters are normally supplied at 200 ohms per volt and rectifier voltmeters are normally 1,000 ohms per volt. Both types can be supplied up to 20,000 ohms per volt if required. Rectifier milliammeters and ammeters have evenly divided scales and all ranges over 100 mA are supplied with small external current transformers.

*Messrs. Taylor Electrical Instruments, Ltd., 419-424 Montrose Avenue, Slough, Bucks.*



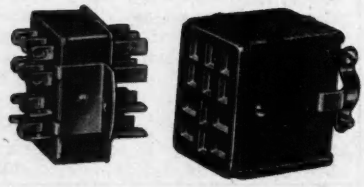

## Multi-Contact Plugs and Sockets

The illustration below shows a miniature 12-way plug and socket to carry 5 amps. per contact at a working voltage of 250, which is fully suitable for operating under tropical conditions at this rating.

A particular feature is the very low contact resistance obtained, which is lower than 0.0005 ohms per contact.

The plugs and sockets can be supplied with mounting brackets or cable termination covers on either portion, and are made with the following numbers of contacts: 2, 4, 6, 8, 12, 18, 24, and 33.

*Messrs. Painton and Co., Kingsthorpe, Northampton.*



## Attenuators and Tapped Resistors

Stages in the assembly of a tapped resistor are shown in the photograph at the head of this page. The resistance elements are wound on thin insulating strips which are held between the mouldings forming the main body of the unit. The upper moulding has a number of nickel-silver studs inset with projecting tags to which the tappings of the resistance elements are connected. Brass parts are heavily plated and the whole component conforms to the Crown Agents' Specification for tropical finish.

The nickel-silver contact brush has two spaced laminations each exerting independent pressure. A spring-loaded ball engages with a toothed wheel to give a positive location of the brush on the contact studs. The series contact resistance is of the order of 0.01 ohm. Studs and brushes of beryllium copper can also be provided, having a lower contact resistance for noise reduction in voice-frequency circuits.

The tapped resistor illustrated has a resistance of 100,000 ohms and measures 2½ in. diameter by 3 in. depth behind panel. Larger sizes are also available with 40 and 60 studs, and the winding can be tapped to a linear or logarithmic scale.

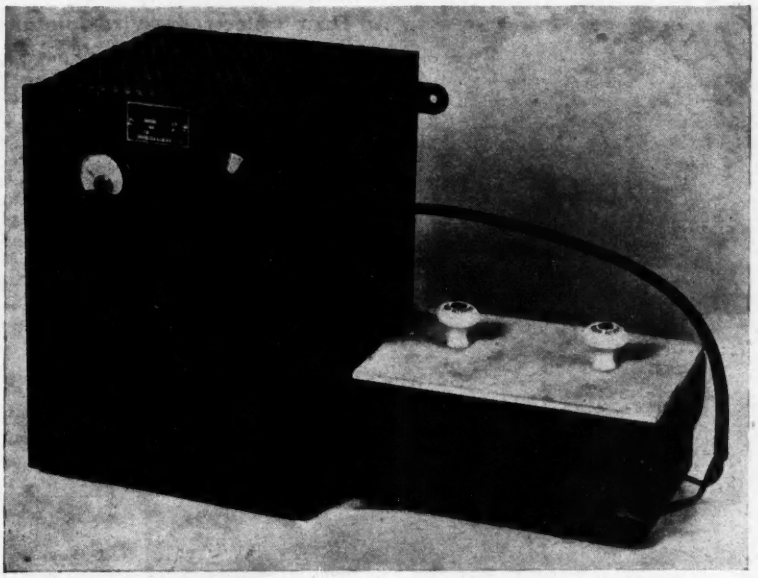
*Messrs. Painton and Co., Kingsthorpe, Northampton.*

## The G. and T. Electrochemical Etching Apparatus

In industrial and engineering works a common problem is to find a means of marking metals. Engraving is expensive both as to time and initial equipment. A marking or stamping press, though rapid, may raise burrs which are not acceptable where fine limits are involved, and acid etching by the use of transfers is slow and expensive.

The G. and T. Electrochemical Etching Apparatus provides the complete solution to problems of this kind. It is simple and cheap, both to install and to operate. Templates (stencils) can be prepared by any typist and a considerable number of articles can be simultaneously marked.

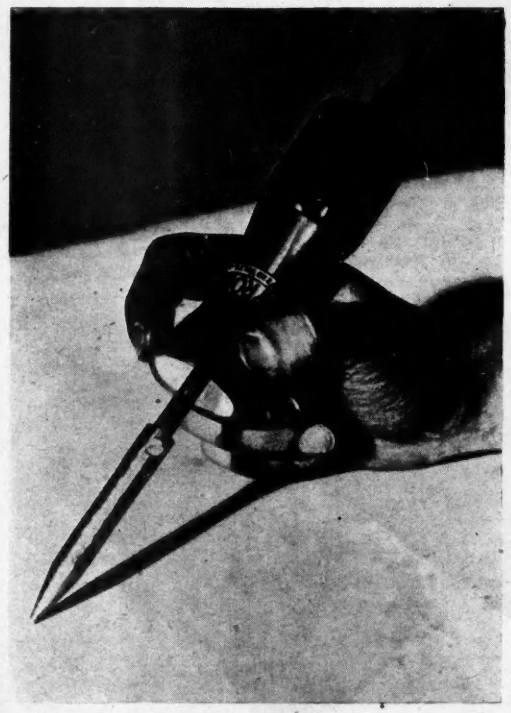
The prime feature of this method is the use of a stencil such as is employed on a duplicating machine. Gestetner "Duroprint" stencils are very satisfactory. The required word or words are typed on to the stencil either once or a number of times with a spacing and disposition sufficient to enable the articles to be laid side by side on the stencil. The prepared stencil is laid, face downwards, on the damped pad, which rests on the lower electrode (cathode). The upper electrode (anode) is then placed in position and the current switched on. In ten seconds clean, sharp etchings on half-dozen small stellite cutters can be produced. 30 seconds may be required if the stencil is heavily worded and the electrodes are loaded to capacity.



**The photograph above shows the G. & T. Etching Apparatus complete with rectifier units for mains operation.**

The stencil is normally good for 15-20 etchings, its life being dependent upon the tendency of the edges of the cuts to become charred during use.

*Messrs. Griffin and Tatlock, Ltd., Kemble Street, Kingsway, London, W.C.2.*



**Pyrobit Instrument Iron, showing the steadiness obtainable when held "pencil-fashion."**

## "Pyrobit" Industrial Electric Soldering Irons

In the making of instruments and for other purposes, it is desirable to have a soldering iron which can be held and manipulated like a pencil.

The ordinary long iron is not suitable for this purpose because if held by the usual handle, the user's hand is too far from the "bit" to allow the desired control of manipulation, whilst nearer the handle the iron is too hot to be comfortably held.

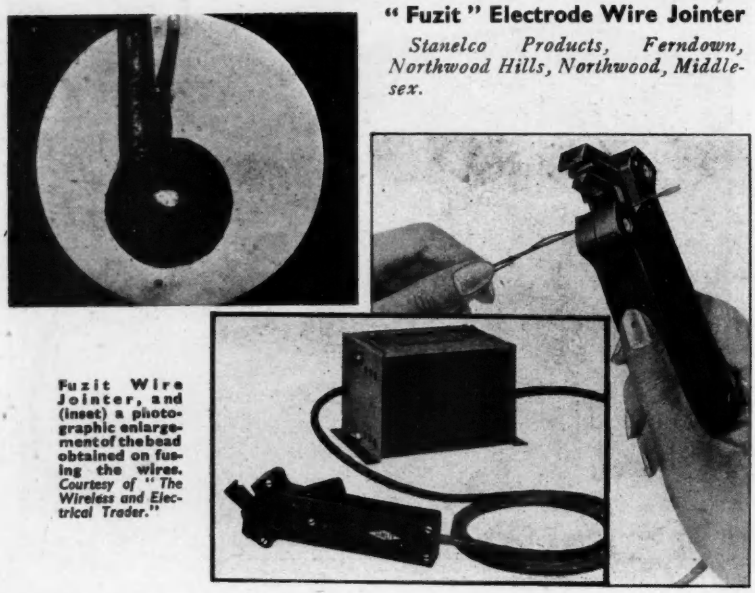
To overcome this difficulty, the handle of the Pyrobit Instrument Iron is internally trumpet-shaped and coated with a heat reflecting paint. Thus the handle does not tend to become unduly hot in spite of the user's hand being so near the copper bit.

These irons can be supplied in voltages from 6 to 250. A great advantage also is that the copper bits are easy to interchange.

*The Acru Electric Tool Manufacturing Co., Ltd., 123 Hyde Road, Ardwick, Manchester, 12.*

## "Fuzit" Electrode Wire Jointer

*Stanelco Products, Ferndown, Northwood Hills, Northwood, Middlesex.*



**Fuzit Wire Jointer, and (inset) a photographic enlargement of the head obtained on fusing the wires. Courtesy of "The Wireless and Electrical Trader."**

The "Fuzit" electrode wire jointer makes it possible to joint fine wires without using either solder or flux.

Jointing can be carried out on copper-copper, copper-resistance wires and resistance-resistance wires. The fusing of the wire forming a perfect joint is carried out in a fraction of a second.

In operation the insulating covering is removed from the wires, whether enamelled or textile. The two wires are twisted together and placed in the slot under the moveable head of the jointer. The trigger is pressed, thus making contact on the wires with the top carbon electrode.

## Rotary Stud Switches

These switches are small and compact and may be used in place of the "wafer" types where a superior component is required. The range comprises switches with up to eight poles, and a maximum of twenty-four studs per pole.

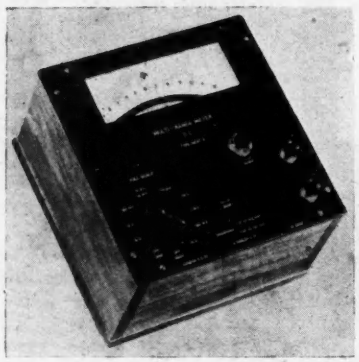
The stud mounting board is a bakelite moulding, roughly elliptical in shape, and thickened at the ends and the centre to provide adequate fixing for the supporting pillars and also a bearing for the brush mounting. The 3/16 in. diameter contact studs are pressed into the board, and are provided with long soldering spills.

The switch resistance as measured from the segment to any of the studs, including the contact resistance, is of the order of 0.005 ohms. The switch can be mounted on a panel by two screws, tapped holes for which are provided in the mounting base. A knob and pointer is included, and a photo-etched dial plate, suitably engraved, can be supplied if required. Metal screening cans which completely enclose the switch are also available for all types. (*See* below.)

*Messrs. Muirhead and Co., Ltd., Elmers End, Beckenham, Kent.*

## Super Sensitive Multi-Range Volt-ammeter

**Type 4237A** ⟶



This instrument has been specially designed for testing circuits of small power, where it is desirable to make measurements without disturbing the circuit to any appreciable extent.

It employs a taut-strip sensitive pointer type moving coil suspension, and is provided with the necessary series resistances and shunts, all of which are controlled by the one circular switch mounted at the top of the instrument to give the current and voltage ranges listed below.

It is mounted in a strong wooden case with a bakelite panel, and is intended to be used with the scale in the horizontal plane. A knife-edged pointer and mirror assists in obtaining precise readings on the 4 in. scale.

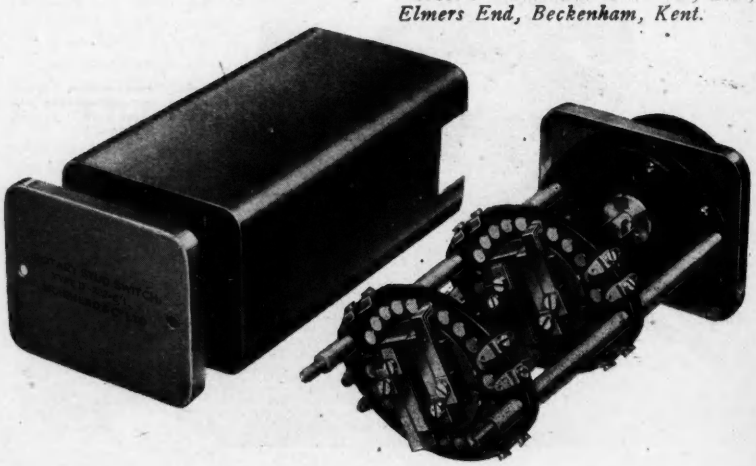
The circuit of the instrument is so arranged that, when used as a voltmeter, the resistance is 100,000 ohms per volt and, when used as an ammeter, the volt drop is 100 millivolts on all ranges.

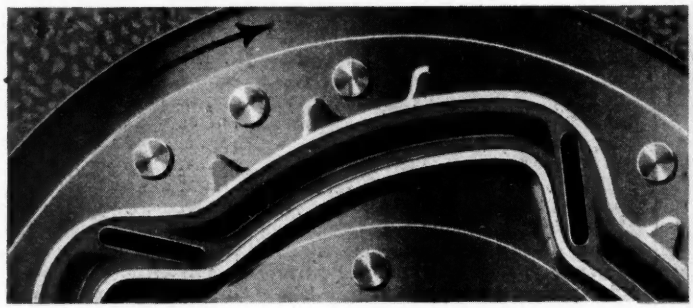
Eleven ranges are provided:—

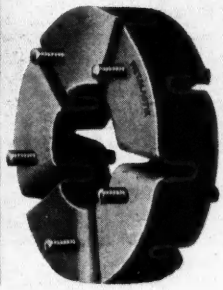
| | |
|---|---|
| 0-10 millivolts | 0-10 microamps |
| 0-100 ,, | 0-100 ,, |
| 0-1 volts | 0-1 milliamps |
| 0-10 ,, | 0-10 ,, |
| 0-100 ,, | |

The size of the instrument is 7 in. by 6½ in. by 4 in. and the weight approximately 4 lbs.

*Messrs. H. Tinsley and Co., Ltd., Werndee Hall, South Norwood, London, S.E.25.*







The 'Z'-type coupling, permitting angular and axial disalignment; cushioned drive with emergency positive engagement. For powers from 1/15 H.P. to many thousand H.P.

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With a different modulus in compression, tension and shear (linear or torsional), natural and synthetic rubber are now engineers' materials of unlimited scope, thanks to our perfect rubber-to-metal weld. This process is being applied to all metals ordinarily in use, including light alloys.

The illustrations on the right show a few of the many specialised Metalastik products, some available in a complete range of sizes; hundreds of thousands of these units are in use, ranging from instrument mountings to torsional vibration dampers.

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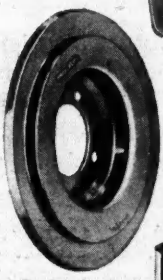
*Metalastik Ltd., Leicester*



The 'Cross'-type elastic mounting; ingenious construction gives equal areas of rubber-to-metal weld on both elements. Used for a great variety of frequencies & sizes, for loads from 1 lb. to 1 ton.

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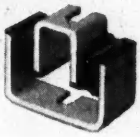
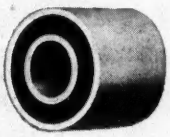
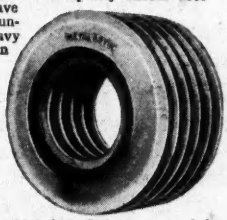


Double 'U' mounting using rubber in shear. Very simple to install, slips under bolt heads. Used in great range of frequencies and sizes.



Metalastik rubber-to-metal welded bush. Rubber gives elasticity in compression, tension, linear or torsional shear, separately or in combination. Increased load-capacity rubber does not leave metal under heavy load. In wide range of sizes.



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# CORRESPONDENCE

## Simplified Symbols

SIR,—The article by your contributor, Mr. Shannon, on symbol simplification, will, no doubt, raise some controversy, and I should like to mention one or two points which Mr. Shannon has apparently missed.

The most important of these is legibility. I beg to submit that the specimen diagram of a superhet (Fig. 13) when compared with the conventional one (Fig. 12), is not nearly as clear to read, and the adjective "messy" can be applied to it. The valves and components do not stand out to the eye as in the case of the top diagram. The comparison is unfair, also, as no lettering is shown in the lower diagram which, if it was inserted, would make it "messier" still. The reason for this "messiness" is because the suggested envelopes for valves are constructed with vertical and horizontal lines—the same as the wiring lines. But if, as is usual, valves are represented by circular or nearly circular outlines, they "stand out" from the rest of the diagram in no uncertain fashion. The rectifier, as shown, at first glance seems part of the wiring.

Surely the main requirement of a theoretical diagram is that it should be easy to "read" and understand, and the extra time expended in making it so is, without a doubt, well spent. One way to make the new symbols suggested more outstanding would be to use lines which were at least twice as thick as the connecting lines, but this would be contrary to the idea of time-saving. Why not use a circle? Describing a circle needs only one operation, whereas a "box" needs four separate construction lines. The average triode, double-diode-triode, pentode, or rectifier can easily be accommodated in a circle of half an inch in diameter (assuming the size of the diagram to be approximately the same as that given in Mr. Shannon's article), and a bigger circle (say, ¾ in. dia.), used for frequency-changer valves.

I have used for some years, with considerable success, some lino-cuts (made by myself) which are circular and contain the conventional symbols. Of course, to cover the whole gamut of types a considerable number of them would be necessary, but I have found that three types cover my modest needs quite satisfactorily. They consist simply of a circular stamp of a triode, a double-grid and a triode-pentode. Any additional electrodes can be quickly inserted after the impression has been made on the paper with the appropriate lino-cut.

The suggested symbols for inductance, resistance, etc., need little comment except that the one for inductance does not *look* like a coil of wire, and will *never* look like a coil of wire, no matter how used we get to it.

I have noticed with alarm that there is a tendency on the part of some British radio and electrical engineers to "Americanise" their diagrams. This is, to some extent, noticeable in Mr. Shannon's article. The practice of drawing the H.T. line mixed up with the rest of the circuit, and not on the top of the diagram, will, I hope, never be introduced in this country.—Yours,

ARTHUR A. LANE-SMITH.

SIR,—Mr. Shannon's proposals for reforming radio symbols are startling at first sight, but if his arguments are sound, they may have some merit. But I would like to suggest that his arguments are not entirely sound for the following reasons:—

For every circuit that a draughtsman produces, the engineer has probably hand-sketched a dozen, and Mr. Shannon's symbols are not easier to draw freehand. I would say that they are rather more difficult and an engineer's time is more valuable than that of a draughtsman. Even from the draughtsman's point of view, I think that the new symbol for inductance would have to be very accurately drawn or it would look unsightly. It is not usual for a draughtsman to put five or six dots for valve grids; two, or at the most, three dashes suffice.

If simplification of the symbols is wanted, I would suggest that there are two changes ready to hand which could be standardised right away. They are already widely used by engineers. The first is the removal of the glass from the valve symbols. We do not draw the tin case round condensers nor the knobs on potentiometers. Any untidiness about a gas-filled valve could be eliminated by replacing the shading by letters sitting on the grid which could be used to denote, in chemist's notation, the type of gas filling—Ne for neon, A for argon, etc.

The other change is the omission of the jump-over at crossing points and the substitution of a dot for a connexion. I am aware of the old argument about errors arising from the accidental omission of a dot, but it does not seem to happen in practice

# CORRESPONDENCE

## Simplified Symbols (*contd.*)

and the amount of time saved is so great that one wonders that its use has not become more general.

Granted these two points, the remaining awkward symbol is the curly inductance. This does not bother the engineer at all and I do not believe that it hurts the draughtsman so much as would the proposed new symbol. It certainly has the merit of being a pictorial representation of the actual coil.

If Mr. Shannon's article leads to further discussion and eventually to some simplification and standardisation among radio engineers, and between radio, telephone and other branches of electrical engineering, it will have been of great value.—Yours faithfully,

W. H. STEVENS.

## Edison and Swan

SIR,—I have read with interest the article appearing in the December issue of ELECTRONIC ENGINEERING, under the heading "Before the Diode," Noting that Mr. Tyne writes "In 1879 Thomas A. Edison finally succeeded in 'sub-dividing the electric light,'" I know you will forgive me pointing out a fact of interest not yet fully appreciated (though it does not in any way detract from the accuracy of Mr. Tyne's article) that it was Swan (afterwards Sir Joseph) who produced the first practical incandescent electric lamp which he exhibited at the Newcastle-on-Tyne Chemical Society on December 18, 1878.

Another item of interest concerns Mr. Tyne's recording that "early in 1882, after the formation of the Edison Electric Light Company of London, John Ambrose Fleming (later Sir John Ambrose Fleming) was appointed electrical adviser to the Company." May I comment that in 1882 there were two companies in England making electric lamps: The Swan Electric Light Co. and the Edison Electric Light Co. Litigation transpired between the two concerns on the subject of patents, which resulted in an amalgamation of the two interests: thus was formed in 1883 the Edison & Swan United Electric Light Co. Since it was many years later that Fleming's investigations of the "Edison Effect" led to the production of the Fleming Diode, the significance of this reference will be appreciated, particularly by English readers.—Yours faithfully,

N. E. MILLER,
Publicity Manager,
The Edison Swan Electric Co., Ltd.

## Discussions

DEAR SIR,—Your Editorial in the November issue very properly emphasises the desirability of and the need for frequent publication of the transactions of meetings covering radio science.

In the field of mechanical engineering, the Institutions of Mechanical, Automobile and Aeronautical Engineers, to mention only three, not only regularly publish proceedings on their respective applications of mechanical science, but also generally co-operate often to the extent of having joint meetings of common interest to the entire membership of the various Institutions.

The Institutions of Civil, Structural and Municipal and County Engineers, likewise propagate knowledge in the vast Civil Engineering field.

Abroad, the Australian and American Institutes of Radio Engineers, work in complete harmony with other professional bodies even to the extent of joint meetings with the American and Australian Institutes of Electrical Engineers. In this country, the Institute of Physics has always been willing to co-operate in the general advancement of radio and electronic science. The British Institution of Radio Engineers advocates such co-operation between the interested bodies throughout the country in order to stimulate development.

The evidence to be found in your various editorials proves conclusively the need for such co-operation, especially if such a comparatively new science as radio is to be properly developed in this country as it has been encouraged in America and Australia.—Yours faithfully,

G. D. CLIFFORD,
*Secretary, British Institution of Radio Engineers.*

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# JANUARY MEETINGS

## Institution of Electrical Engineers

### Measurements Section

On January 21, at 5.30 p.m., a meeting will be held at which a paper entitled "A New Electronic Stabilizer and Regulator for D.C. Voltages" will be read by A. Glynne, M.A.

### Wireless Section

At 5.30 p.m. on Tuesday, January 18, the meeting will take the form of a Discussion, opened by J. A. Smale, B.Sc., on "Comparative Merits of Different Types of Directive Aerials for Communications."

### Informal Meeting

The meeting to be held at 5.30 p.m. on January 24 will be an informal discussion on "Industrial Applications of Radio-Frequency Methods of Heating." This discussion will be opened by Mr. N. R. Bligh.

### Students Section

A visit has been arranged for Saturday, January 22, at 2.30 p.m., to Fulham Power Station. Details may be obtained from the Secretary, I.E.E.

"Problems Night" will be held on Monday, January 17, at 7 p.m., at the I.E.E., Savoy Place.

## North Western Centre

### Wireless Group

An informal discussion will be held by the above Group at the Engineers' Club, Albert Square, Manchester, on Friday, January 28, at 6 p.m. The subject will be "Transient Reproduction," opened by G. J. Thomas, B.Sc.

## British Kinematograph Society

On January 12, at 6 p.m., a joint meeting with the R.P.S. Kinematograph Section will be held at the Gaumont-British Theatre, Wardour Street, W.1.

The lecture will be given by R. Howard Cricks, F.R.P.S., on "The Design of Sub-standard Sound Projectors."

## Brit. I.R.E.

The next meeting of the above will be held at the Institution of Structural Engineers, 11 Upper Belgrave Street, London, S.W.1, on January 27, at 6.30 p.m. A paper on "Some Aspects of Special Electron Tubes" will be read by Mr. F. E. Lane.

## Institute of Physics

### Electronics Group

A joint meeting with the Midland Branch of the Institute of Physics will be held in Birmingham on January 22, at 2.30 p.m., at the University, Edmund Street (in the centre of the City).

The meeting will take the form of a discussion on "Space-charge and Noise in Radio Valves," introduced by Dr. P. B. Moon and Dr. R. R. Nimmo.

# ABSTRACTS OF ELECTRONIC LITERATURE

## TELEVISION

### Cathode-Ray Control of Television Light Valves

*(J. S. Donal, Jr.)*

When a light valve is employed for the reproduction of television pictures, it is desirable to make use of a cathode-ray beam to control the light valve in order to preserve the all-electronic character of the television system. A number of procedures of cathode-ray control are described, the majority of which are applicable particularly to the control of the suspension light valve.

The general method employed is shown to be the production of an electric field through the light valve by bombarding one side of the valve with electrons of very high velocity, causing the valve areas to be charged in a negative direction toward the limiting potential of the bombarded surface. Removal of the electric field is then accomplished by charging these areas back toward their original potential by the use of substantially reduced velocity.

The most elementary procedure described is one in which a single beam of electrons of constant velocity is employed, discharge being accomplished by secondary electrons generated by the action of theh beam of primary electrons.

The effects of polarisation of the light valve, resulting from the comparatively low resistivity of the suspension, are described and explained. It is shown that a suspension of such low resistivity as to be uncontrollable by the other procedures may be made operative when the valve is used in combination with a spatially modulated electron spray and when, in addition, the potential of one wall of the valve is increased and decreased at a moderate frequency.

Of the procedures described, the most effective from the practical standpoint is shown to be one in which the light-valve field is developed by a scanning beam, and in which the field is later removed by rescanning with the same beam at a reduced electron velocity. A photograph is shown of a picture reproduced by the light-valve when controlled by this method.

—*Proc. I.R.E.*, May, 1943, p. 195.

## MEASUREMENT

### An Electrical Tube Gauge

*(E. Fawssett)*

Apparatus is described for measuring rapidly the internal diameter of long tubes. By means of a sensitive rectifier-operated voltmeter, an indication is obtained of the voltage induced in a small coil on an armature moving in and out of the gap of an electromagnet supplied with a known current, the armature being connected by a simple lever to a gauging roller supported on a "cartridge" which is free to slide up and down inside the tube. The speed with which readings can be obtained is pointed out and test results are given of work done with the instrument in the boiler house of a power station of the North-Eastern Electric Supply Co., Ltd.

—*Engg.*, 15/10/43, p. 301*

### The Radio-Frequency Capacitometer

*(F. J. Moles)*

The radio-frequency capacitometer described was designed to overcome the difficulties encountered in using ordinary bridge methods. The principle of operation is based on the comparison of the frequencies of two radio frequency oscillators, one having a fixed frequency and the other being variable. In capacitance measurements a substitution method is used and the value of the unknown capacitance is read directly from the scale. For inductance measurement, the unknown inductance is connected in series with the variable-oscillator inductance, the frequency brought back to its original value by adjusting the precision capacitor and the results read from a curve. The ranges of measurement are 0 to 1,000 $\mu\mu$F and 0 to 1,000 $\mu$H.

—*G. E. Rev.*, August, 1943, p. 457.*

### A Sensitive Cathode-Ray Voltmeter

*(Z. V. Harvalik)*

When 1 volt is applied on the deflection plates of an R.C.A. 931 tube there is a deflection of the beam on the screen of 0.16 mm., the current is $3.0 \times 10^{-8}$ ampere. To determine this small deflection a microscope with a magnification of 200 times is used. An eyepiece micrometer of 100 divisions (1 division = 2 mm. at the distance of 25 cm.) is used to standardise the device. The standardisation itself is performed by applying known potentials to the deflection plates. One division in the eye-piece equals 0.045 volt, and a current flow of $1.0 \times 10^{-8}$ ampere is observed.

—*Rev. Sci. Inst.*, Vol. 14 (1943), p. 263.

### An Electronic Voltmeter for High Voltages

*(W. Ehrenberg and H. Hirsch)*

A simple new cathode-ray tube is described with which voltages up to about 50 kV can be measured directly: its current consumption is very small and the only accessory required is a filament transformer.

—*Jour. Sci. Inst.*, Vol. 20 (1943), p. 161.

## INDUSTRY

### Polystyrene for Wartime Electronics

*(F. E. Wiley)*

The properties of a good high-frequency insulating material are listed. It is pointed out that polystyrene as now produced possesses many of these properties although previously it was often rejected because its initially transparent surface tended gradually to assume a white frosted appearance on ageing. It was discovered that this "frost" was composed of minute cracks in the surface and was caused by volatile impurities and residual monomeric styrene. Current methods of production are claimed to have eliminated this defect. Better moulding technique is stated to have reduced the danger of failure due to the difference in strength in the direction of orientation and the direction perpendicular to it. The importance of correct machining methods is stressed and details are given of sawing, drilling, turning, milling, threading and tapping of polystyrene.

—*Mod. Plastics*, August, 1943, p. 80.*

### High-Frequency Glueing of Resins

*(W. Godfrey, P. H. Bilhuber)*

Electric high-frequency heaters used by Steinway & Sons in glider construction are described. The advantages of high-frequency heating for this type of work are stressed, and the perpendicular, parallel and stray field heating methods for introducing heat into glue lines or a mass of material are discussed. The use of high-frequency heaters for wood drying is pointed out. Calculations are given for the time required to heat a quantity of wood of known specific heat and for the load capacity of high-frequency heaters.

—*Mod. Plastics*, Sept., 1943, p. 89*

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The filter consisting of inductance elements $L_1$ and $L_2$ and capacity elements $C_1$ and $C_2$ is shown arranged in an amplifier circuit in Fig. 1. The

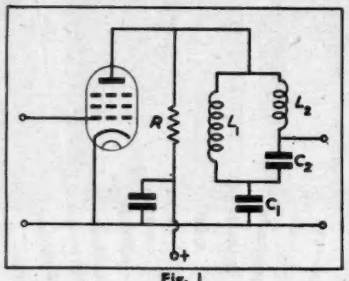


Fig. 1

amplifier valve is of high impedance tetrode or pentode type with anode-load resistance $R$ and associated decoupling condenser and the filter circuit is arranged across the resistance $R$. The filter consists of two branches, that formed by the series connexion of the inductance $L_1$ and capacity $C_1$ and that formed by the like connexion of inductance $L_2$ and capacity $C_2$. The input to the filter is applied across the ends of the former branch and the latter branch is connected across the inductance element $L_1$ of the former. The output is taken from across the two capacities.

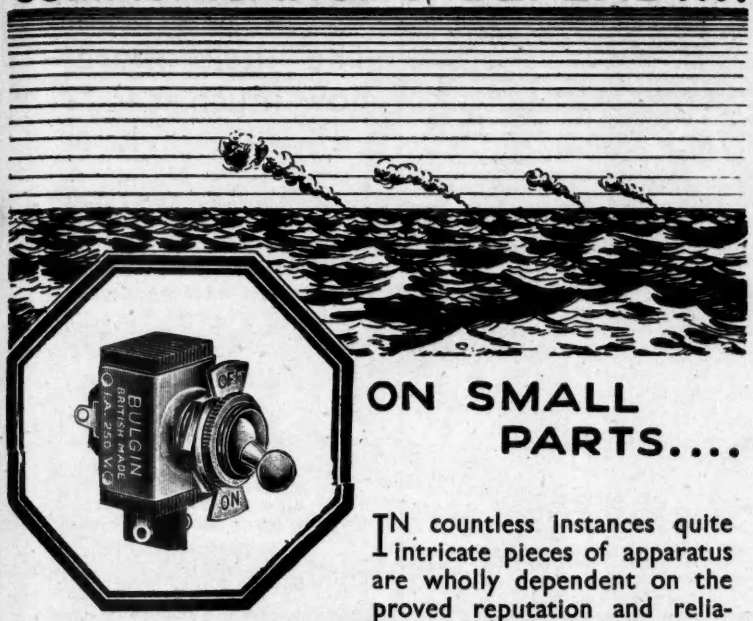
The transfer characteristic of the circuit arrangement is in general terms that of the driving valve operating into an anode load impedance consisting of the capacity $C_1$ alone, but modified by a resonance and an anti-resonance. The resonance is that of the circuit formed by the elements $L_1$, $L_2$ and $C_2$ and the anti-resonance occurs at a lower frequency given by

$$1/2\pi\sqrt{L_1C_1 + L_1C_2 + L_2C_2}$$

To obtain the desirable qualities outlined above the inductance elements $L_1$ and $L_2$ are chosen of the same order of magnitude. On the other hand, the capacity elements $C_1$ and $C_2$ are chosen widely different. For instance, $C_1$ may be chosen as 60 $\mu\mu$F and $C_2$ as 4 $\mu\mu$F. In these circumstances the anti-resonant frequency is dependent almost solely on the elements $L_2$ and $C_2$, and since $C_1$ is large it is hardly affected by any stray capacities that may exist in the circuit. Since $C_2$ is small the resonant frequency $f_2$ is widely separated from the anti-resonant frequency $f_1$ and a wide-band transfer is obtained. The presence of the resistance $R$ assists in obtaining a level characteristic between the two frequencies $f_1$ and $f_2$.

The resistance $R$ may be 100,000 ohms in value.

# COMMUNICATIONS DEPEND....

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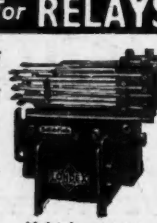

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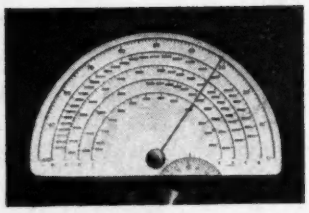
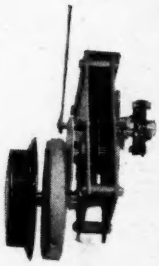


### DIAL CALIBRATION

The above photograph gives a clear idea of the manner in which the dial is marked. Four coils have direct calibration and the remainder are referred by graphs to the outer scale. The small Logging Scale is gear driven from the Drive Mechanism and, therefore, positive in action. By quick reference to the outer scale and the pointer reading thereon, and the reading of the logging scale, it is possible to return to any given point at any time quickly and accurately further, any number of stations working on fixed wavelengths can be logged and returned to for operational purposes.



### TUNING DIAL DRIVE MECHANISM

Utilises a flywheel drive and spring loaded Tufnol gearing, giving a ratio of approximately 70—1. The gearing is driven through a friction disc and so arranged that when the pointer, which is attached to the shaft driving the gang condenser, is either at zero or 100 terminating point of travel, the small stop-pin prevents further movement of this shaft and the friction drive acts as shock absorber, removing strain from the Tufnol gears themselves.

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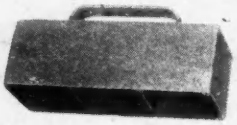
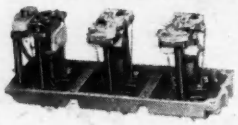
High-efficiency coils mounted in die-cast screening containers.





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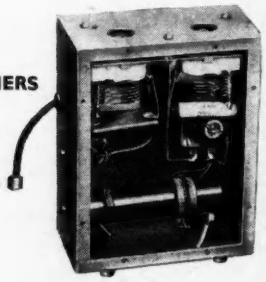

Tuning ranges :

| Range | Kc/s. | Range | Kc/s. |
|---|---|---|---|
| A | 22,000—31,000 | F | 600— 1,250 |
| B | 9,000—22,000 | G | 300— 600 |
| C | 4,500— 9,000 | H | 150— 300 |
| D | 2,100— 4,500 | I | 90— 150 |
| E | 1,250— 2,100 | J | 40— 90 |

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